June 2016

# i wonder...

## REDISCOVERING SCHOOL SCIENCE

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## INTERACTIONS IN OUTER SPACE

### How the Universe reveals itself

A publication from Azim Premji University

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i wonder...
Rediscovering school science



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## Editor's Desk

What does wonder have to do with a magazine for middle school science teachers?

Well, as biologist Richard Dawkins writes, wonder has for long been recognised as the 'wellspring of all scientific inquiry', motivating scientists to investigate rainbows, the night sky, and other strange phenomena. But, studies like those of primatologist Jane Goodall's with wild chimpanzees indicate that they too are capable of this child-like wonder, for example, at the sight of a beautiful waterfall. Does this mean that our capacity for this emotion is no different from that of our closest relatives? Or that Francis Bacon was right in suggesting that wonder only arises out of a mystified ignorance that science alone can cure? Hardly! While we may share our sense of wonder for natural phenomena with higher primates; we now have reason to believe that as a culturally mature species, no longer pre-occupied with the necessities of survival, we are also capable of a more evolved form of this emotion. One that is reflected in our craving to understand these phenomena through the unique process and perspective offered by science, or what Charles Darwin called 'this view of life'. Thus, far from 'curing' us of wonder, scientific discoveries are themselves wondrous, deepening our excitement and delight in the mystery and grandeur of the natural world!

Middle school marks a period of remarkable transformation. Youngsters enter middle school as children, full of wonder and excitement. And leave as young adults, who with opportunities to discover the wonders of science, may be inspired by a lasting sense of meaning for its cause. One that, in conservationist Rachel Carson's words, acts as 'an unfailing antidote against the boredom and disenchantments of later years, the sterile preoccupation with things that are artificial'. We see *I wonder* as an attempt to bring together a community of writers and readers willing to share their experience of engaging with just such a cultural shift in school science. One that, as theoretical physicist Brian Greene urges, 'places science in its rightful place alongside music, art and literature as an indispensable part of what makes life worth living'.

Our 2nd issue is book-ended by two themes that celebrate this sense of wonder. **Interactions** is all about perspective, inviting readers to view the world through the lens of scientific explanations that unify seemingly disparate phenomena into a seamless whole. We explore the underlying forces (The Fundamental Four and Material Interactions) and cues (Chemical Ecology: Talking in Nature's Language and How to build a Nervous System) that shape the dynamics and behaviour of systems as distant as galaxies (Interactions in Outer Space) and as immediate as our immune system responding to the ubiquitous common cold (A Viral Handshake).

**Emerging Trends in Biology**, on the other hand, is more about process. How are the big questions in Biology and breakthroughs in method shaping the scope of future scientific inquiry and the nature of this discipline? We give you a peek into the latest in our understanding of memories (We are what we remember), relationship with gut bacteria (We have Company), and genetic clues to evolutionary history (Reconstructing the History of Life).

In an on-going effort to bring new perspectives and voices, this issue also presents nineteen new authors and three new sections – Research to Practice, The Science Teacher at Work, and Science Communication. Go ahead - dive in! And, don't forget to send your feedback to us at iwonder.editor@azimpremjifoundation.org.

**Chitra Ravi**
**Co-editor.**

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# INTERACTIONS IN OUTER SPACE

## How the Universe reveals itself

ANAND NARAYANAN

From the discovery of alien worlds and the creation and evolution of galaxies to the reality of a dark side to the universe, cosmic interactions have been the golden key for unlocking many secrets about the universe. Through different examples, this article highlights how interactions between objects of outer space have constantly fulfilled our longing to make sense of the world around us.

Outer space is a lonely place. Stars are separated from each other, for the most part, by sheer emptiness. To appreciate how far apart things are in the universe, consider this example. Imagine the Sun as the centre of an expanding sphere. This imaginary sphere will have to grow to a radius of 38,000,000,000,000 kilometers before it can make contact with its **nearest** star. And that can take no less than about 4 years, even if the sphere were to expand at the speed of light!

The matter that does exist between stars is in a very diffuse state. The interstellar (space between stars) matter is so scattered around that on average there is barely about 1 atom per cubic centimetre of it. This is roughly thousand times wispier than even the best vacuum produced in laboratories here on Earth. Going by such staggeringly low numbers, it is easy to think of outer space as a tranquil world, where everything is isolated from the rest.

Interestingly, while the universe may not be a place of great turmoil, it is not a place of stagnation either. Even in this seemingly desolate space, many interactions occur, often in very significant ways.

These interactions are possible as a result of one of the most pervasive forces in the universe. This attractive force exists here on Earth, as well as in outer space. It can act between any two objects with mass - be it particles, people or planets. For two objects to feel this force, they do not have to come into physical contact with each other. The force can act over extremely large distances. By now, you may have guessed, and guessed it right that we are referring to the force of gravity, one of the four fundamental forces in the universe (see Box 1).

**Box 1.** Physicists have grouped forces in Nature into four fundamental categories. These are the weak force, the strong force, the electromagnetic force and the gravitational force. Of these the weak and the strong forces are of significance only when we are describing interactions at scales smaller than the size of an atom. Gravity (and electromagnetic forces) on the other hand, can act over vast distances - from very near to very far, and between all masses - from atomic particles to giant galaxies. This attribute of gravity makes it the force that predominantly shapes our physical universe and governs its course of evolution. Gravitational interaction is also what allows us to study the properties of the universe in great detail.

For a short description of the four fundamental forces, see: http://www.quirkyscience.com/four-fundamental-forces/, or this http://shasthram.com/youngscientist/fundamental-forces-of-nature.

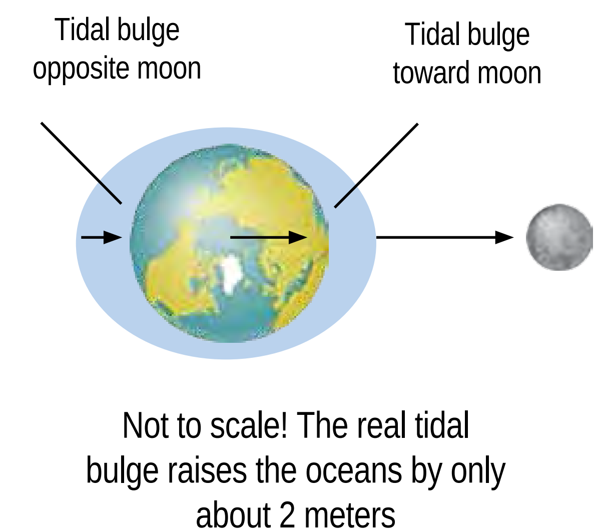



**Figure 1.** The formation of tides on Earth as a result of the Moon's gravitational pull. Source: Bennett et al.

Heavenly interactions are less obvious to us because, firstly, they happen out in the far depths of space, away from our usual gaze. Secondly, the time scales over which these interactions unfold, as we will see later, are not of the order of seconds, minutes, hours or a few days. Certain interactions are so dreadfully slow that it would take several human life times to perceive the outcome. Yet scientists have taken great pains to understand these interactions, not just because they are fascinating, but because they offer very useful insights into the way our universe works. This article highlights a few different scenarios of cosmic interactions, played out on different physical scales, from the astronomically small to the very large, from the very near to the very far.

## Interactions within our neighbourhood

Let us start with an example that is simple and familiar.

At just over 400,000 kilometers, the Moon is a place not too far from home. Of all the celestial objects we are familiar with, the Moon (along with the Sun), has the most bearing on life here on Earth. People who live along coastlines are well aware of how tides turn strong twice every day and more aggressively so during the new moon every month. Interestingly, the rise and fall of tides have very little to do with anything internal to the ocean. That the high and low phases of tides coincide with certain specific phases of the moon indicates that it is the interaction of the Moon with the Earth that is the basis of existence of tides (refer Fig. 1). This interaction is through the force of gravity.

The water in the Earth's ocean on the near side (i.e., the side of the Earth closer to the Moon) gets pulled by the Moon's gravity, thus causing the water in the ocean to bulge out. But this water is also simultaneously getting pulled back by Earth's gravity, causing it to lash out on the sea shore as high waves.

Interestingly, a similar bulge also develops on the opposite side of the Earth. Unlike on the near side, this bulge is caused by inertia. Unlike solids, water is sluggish in movement. If you have ever played with water in a cup, you may have noticed this yourself. As you move the cup, the water in it shows a tendency to stay behind. Similarly, as gravity causes the Earth to feel a drag towards the Moon, the water in the ocean shows a tendency to stay where it is. The result is a tidal bulge on the far side (the side of the Earth that is not facing the Moon).

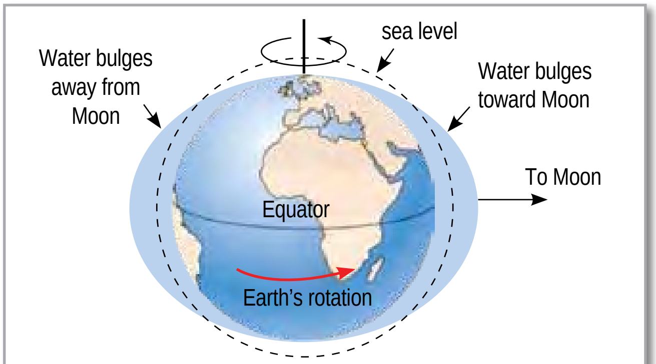



**Figure 2.** The Earth's rotation ensures that all geographical locations experience high tides.

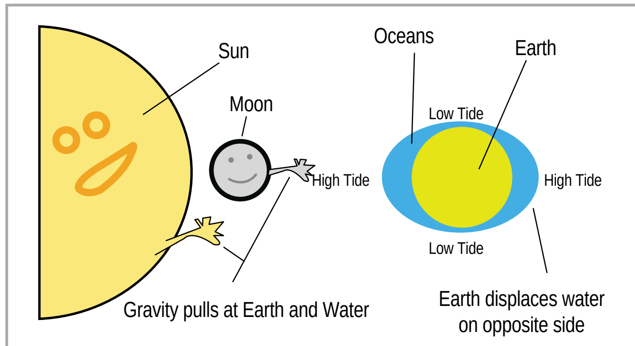



**Figure 3.** The most intense high tides are formed during the New Moon Phase, when the Moon and the Sun are on the same side of Earth.

The Earth's rotation ensures that all geographical locations experience these two tidal bulges once during a day–night cycle (refer Fig. 2). Thus, every coastline on Earth will face high tides twice in 24 hours. Of course, not all coastlines will experience the same intensity of tides. The force of tides will also depend on the shape of the coastline, the strength of winds, ocean currents and other, more local, factors. We have attempted to explain only the most dominant among these factors in the formation of tides.

**Box 2:** Gravitational forces are always attractive. The force of gravity between two or more objects depends on the mass of each object and the distance separating them. Expressed mathematically:

$$\mathbf{F = G\,M\,m/r^2}$$

**M** and **m**, here, are the masses of the two objects and **r** is the distance between them. G is a constant number, called the universal gravitational constant. From this equation it is evident that the gravitational force between two objects weakens as the separation between them increases. Similarly, if the objects are tiny in their mass (atoms, for example), then the gravitational force between them is going to be feeble even when they are very close to each other.

**Suggested Task for Students:** Keeping **M** and **m** as fixed values, and assuming G = 1, ask students to plot a graph that shows how the force of gravity between the two masses would vary with increase in distance between them. This can be done in an excel sheet.

What about the gravitational interaction of the Sun with the Earth? Is that of any consequence for tides on Earth? As it turns out, the Sun plays a lesser role in the ebb and flow of tides. Though a million times more massive than the Moon, the Sun's gravitational tug on Earth is only one-third that of the Moon because of the Sun's greater distance from us (see Box 2).

Try out this interactive animation on tides, from the University of Nebraska, to understand the effect of the Moon and the Sun on Earth's oceans: http://astro.unl.edu/classaction/animations/lunarcycles/tidesim.html.

Interestingly, tides become most intense when the Sun and Moon are aligned on the same side of the Earth (as shown in Fig. 3.). This is because the Earth now experiences gravitational forces from both the Moon and the Sun, acting in the same direction. This occurs every new moon; thus the tides at this time of the year are at their maximum intensity.

## Interactions aiding our search for alien worlds

From the immediate reaches of our solar system, let us turn our attention to a different example, to a different physical scale, where observing the gravitational interaction between astrophysical objects have yielded some captivating discoveries about worlds beyond the solar system, some similar to Earth, and some very different.

Of all the big questions that human kind has ever been interested in, the most fascinating one is – are we alone in this universe? Can life emerge and evolve beyond the confines of Earth?  Could there be other worlds, beyond the solar system, teeming with life? Generations of humans have speculated on questions like these. But it has only been in the last 20 years or so that we have made some scientific forays into answering them.

At present, we have no strong evidence for the presence (or absence) of life beyond that on Earth. But scientists realize that the first indication of life may be in finding an environment outside the Earth that is suitable for life. Life, as we know it, requires the comforting settings of a planet - a thick atmosphere, presence of liquid water, and a steady source of energy in the form of light and heat from a star. With these prerequisites in mind, the search for life elsewhere is presently focused on discovering planets around other stars.

Finding extra-solar planets (planets outside the solar system, also called exoplanets) is a very challenging task. Firstly, even the nearest stars are several light years (a light year is the distance that light travels in one year. Light travels through empty space at a speed of 300,000 kilometers every second. One can easily calculate how many kilometers a light year would be) of distance from us. At these distances, stars look like dots even through telescopes, not to mention their planets, which are typically a few hundreds to a few thousand times smaller than stars. Secondly, a star is a billion times brighter than a planet. What this means is that when we look at a distant star–planet system, for every billion photons (light particles) we receive from a star, one photon reaches us from the planet. The contrast in difficulties is similar to searching for a fire-fly (planet) next to a flood light (star).

Thus, snapping a photograph of an extra-solar planet with a telescope and a camera is rarely feasible. Does this mean that we can never hope to find planets beyond the solar system? Fortunately not! As it turns out, the interactions between a planet and its host star offer us some alternative ways of discovering them.

We generally understand a star-planet system as one where the planet is revolving around the star. But gravitational interaction is mutual. The planet will also exert some amount of gravitational force on the star. If the planet is sufficiently massive and close to the star, this force can be large enough to compel the star to move from its position (see Box 2).

Here is how this happens: in any star–planet system, the star and the planet orbit around a common centre. The common centre is the point where the mass of the star and the planet would be evenly balanced, as if they were on a see-saw. This common center is called the center of mass (see Box 3). The center of mass can be offset from the center of the star. As the planet revolves around the star, the star in turn moves around the center of mass in a periodic manner. As seen from telescopes on Earth, the star would appear to vacillate back and forth. By carefully measuring this wobbly motion of the star, astronomers are able to infer basic attributes of the extra-solar planet, such as its mass, the time it takes to complete one full revolution around the star, the planet's orbital distance from the star, and so on. What is important to remember is that we are not looking at the extra-solar planet directly; instead we are inferring its presence by observing the effect of the planet's gravitational interaction with the star.

Using this technique, in 1995, astronomers discovered the first planet outside of the solar system - around a star called 51 Pegasi, which is about 50 light years from us. Since then, the numbers of extra-solar planet detections have rapidly increased.  Today, we know of the existence of more than 2000 planets beyond the boundaries of the solar system, orbiting various stars in our Galaxy. Most of these discoveries have happened because we are able to observe stellar wobbles caused by the gravitational interaction of planets around them.

Astronomers are now of the opinion that planets are widespread in our universe. Most stars possibly have one or more planets circling around them. Discovering these planets is just a matter of making careful observations.

The recent flurry of scientific discoveries of exo-planets has rekindled a lot of hope and hype on the possibilities of finding life elsewhere in the universe. If planets are as common as stars in our universe, couldn't there be at least one resembling our Earth, with a protective atmosphere, liquid water on its surface, and other conditions conducive for complex life? If conditions are favourable, can life emerge spontaneously in these other worlds? Can there be other sentient beings like us in some of these alien worlds asking such profound questions? We do not know yet, but thanks to gravitational interactions we at least know that there exist worlds beyond the solar system that are potentially habitable. That's one step closer to the answer.

**Box 3. To understand where center of mass falls for a two-body system,** consider the following example. Take two spheres of the same mass. If the spheres were pegged onto the ends of a rod, where would you support the rod for the weight of the spheres to be evenly balanced? Common sense tells us that it will have to be at the centre of the rod, half way from either sphere.

What if one of the spheres happened to be 10 times more massive than the other? You will have to support the rod at a distance 10 times closer to the more massive sphere to balance the system. If you provided support at any other point, the configuration will not be stable.

Mathematically, the center of mass is the point where:

Mass of object 1 x distance from center of mass to object 1 = Mass of object 2 x distance from the center of mass to object 2

$$m \times a = M \times b$$

Let us now look at a star–planet system. In a typical star–planet system, the star is most likely several thousand times more massive than the planet. Thus, the center of mass will have to be closer to the star compared to the low mass planet for the configuration to be stable.

From the equation, we can see that the location of the center of mass is going to depend on the ratio of the mass of the star to the planet. The higher this ratio, the closer the center of mass is to the star. In some cases, the ratio will be such that the center of mass will be within the star.

Since the star and the planet have to circle the center of mass, the lower mass planet will assume a larger orbit and the higher mass star a smaller orbit. For the system to be dynamically stable, the star and the planet have to beat opposite sides of the center of mass, at all times (see Fig. 4). For this to happen, the time it takes for them to complete one full orbit around the center of mass has to be the same. In other words, the planet has to move faster, and the star slower.

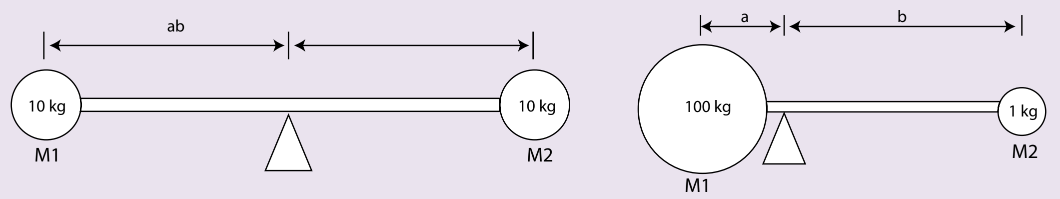
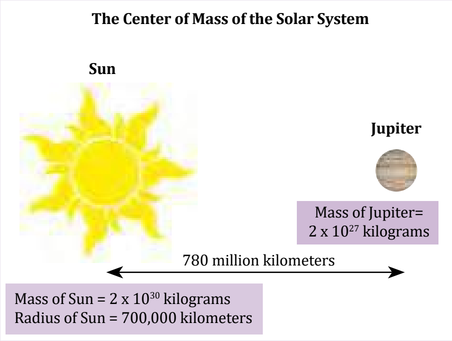



**Figure 4.** What is/isn't allowed for dynamic stability.

Refer this website for an interactive tool on the concept of center of mass: http://astro.unl.edu/naap/esp/centerofmass.html And this one for an illustrative video on the stellar wobble and how astronomers use it to discover extra-solar planets: https://www.youtube.com/watch?v=rN7uuqLKv0I

**Suggested activity:** It is easy to calculate the centre of mass of any system. As an example, try to find out where the centre of mass of the solar system is? To keep the calculation straightforward, think about only the two most massive objects in the solar system, the Sun and the planet Jupiter. Jupiter, though a huge planet when compared to Earth, is still a thousand times less massive than the Sun. Thus, we should expect the centre of mass of the solar system to be closer to the Sun. Use the information given in the graphics to figure out where the centre of mass of the solar system could be.



## Galaxies and their violent interactions

From extra-solar planets, let's journey further out to the scale of galaxies, and witness some, more dramatic, interactions at a much larger scale. Galaxies are huge collections of stars. A galaxy like the Milky Way typically has about a few hundred billion stars within it. A countless number of such galaxies exist in our universe – differing widely in their size, shape and brightness. Astronomers spend a lot of time trying to understand how different galaxies have acquired these shapes (see Box 4).

**Box 4:** Shapes and sizes of galaxies: The way the stars are distributed within a galaxy gives it its particular morphology. Over the years, astronomers have made several attempts at classifying galaxies based on their observed shape. Based on their work, the two predominant classes of galaxies are:

a. Spirals: galaxies that have a disk-like shape with a spiral sub-structure to the disk.

   Visit this site to see beautiful pictures of spiral galaxies: https://www.noao.edu/image_gallery/spiral_galaxies.html

b. Ellipticals: galaxies that have an elliptical or spherical shape. Unlike spiral galaxies, elliptical galaxies are pretty much featureless. They look like a ball of stars.

   Here's an image gallery of elliptical galaxies: https://www.noao.edu/image_gallery/elliptical_galaxies.html

Other than their acquired shape, there are plenty of differences between spiral galaxies and elliptical galaxies. Astronomers are still trying to understand these differences. By looking at a large number of galaxies and their mutual gravitational interactions, astronomers have come to the conclusion that interactions between galaxies play a crucial role in the shapes they assume.

In the immensity of space, some galaxies are found in isolation, while most galaxies tend to huddle in groups. Within a volume spanning a few million light years, it is common to find several thousand galaxies together (see Fig. 5.). They are held this way by their mutual force of gravity.  Such collections of galaxies are called galaxy clusters. There are many such clusters in our universe.

**Figure 5.** This is a Hubble Space Telescope image of the Coma cluster, a cluster of galaxies roughly at a distance of 320 Million light years from us. Every elongated source of light we see in this picture is a galaxy with countless billions of stars within it. The galaxies in this cluster are relatively near each other in space (astronomically speaking) and therefore are moving under the influence of each other's gravitational force.

Each galaxy within a cluster gets pulled on by the other galaxies within the cluster. This means that these galaxies cannot remain stationary. They move in random directions, constantly steered by the combined gravitational pull of all the other galaxies that belong to the cluster.

Movement in an overcrowded environment can often lead to unpleasant scenarios. For example, two or more galaxies can bump into each other. The outcome of such encounters is often spectacular. Astronomers have found numerous examples of galaxies in a cluster engaged in such interactions (refer Box 5). Such galaxy–galaxy interactions are sometimes loosely termed as collisions, which is not really the best word to describe them. The word 'collision' conjures up an image of some very violent and rapid phenomena. In reality, interactions between galaxies are slow, and for the most part, not very violent.

Galaxies are large structures, with a lot of empty space between stars. When they run into each other, individual stars in either galaxy are unlikely to collide with each other. Instead, much like the tides in the Earth's oceans, gravitational forces tug and drag interstellar gas clouds and stars away from their position, creating long tails, streams and plumes (remember, gravity can act over huge distances without physical contact). This is similar to a gravitational tussle, a kind of slow tearing apart of either galaxy engaged in the tidal interaction.

**Figure 6.** This image shows two spiral galaxies that are at some stage of interaction with each other. Such interactions often result in the creation of tail-like features, as seen in this image. These features are formed by streams of stars and interstellar gas dragged out from each galaxy because of their mutual gravitational pull. Although the two galaxies are moving with speeds of several thousand kilometres every second, because of their large sizes and the large distances that separate them, the entire interaction happens over time scales of several millions of years. Credits: Hubble Space Telescope.

Astronomers therefore prefer to call such interactions - mergers. Tidal tails (as seen in Fig. 6) are a tell-tale feature of interacting galaxies.

These interactions can often cause vast distortions in the structure of galaxies. When two spiral galaxies merge fully with each other, the resultant galaxy will be a bigger, more massive galaxy without any distinct sub-structure (like an elliptical galaxy). Could the elliptical galaxies that we see in the universe therefore be a product of the mergers of spiral galaxies? Observational evidence seems to suggest this. By studying galactic interactions, astronomers are learning new facts on how galaxies acquire their peculiar shapes, and how those shapes evolve over astronomically long periods of time.

## The dark side of the universe

We now move to one final example of cosmic interactions. This is also the story of one of the current big mysteries in astronomy. There is mounting evidence suggesting that most of our universe is made of some kind of exotic matter that does not shine, or cast any shadow. It does not interact in any other way with the universe, except via gravity. No one has any specific idea about what it is, and yet we know it exists everywhere. To find out how astronomers came about discovering this mysterious component of the universe, we need to go back to the galactic clusters that we talked about in our last example.

In the early 20th century, the astronomer Fritz Zwicky (refer Fig. 7.) carried out some painstaking measurements on the speed with which galaxies were moving inside a cluster. For his study, Zwicky chose one of the nearby galactic clusters - the Coma cluster (refer Fig. 5).

Zwicky knew that each galaxy's motion was due to the gravitational pull that it felt from the total mass within the cluster. Thus, he deduced that by measuring the speed of different galaxies, he would be able to infer the total mass of all the galaxies of the cluster.Zwicky

**Figure 7.** Fritz Zwicky was a famous Swiss-born American astronomer who made several brilliant discoveries and predictions, including the gravitational effects of dark matter. For most of his career, he served as faculty at the California Institute of Technology. For a brief biographical sketch of Zwicky, refer: http://www.slac.stanford.edu/pubs/beamline/31/1/31-1-maurer.pdf

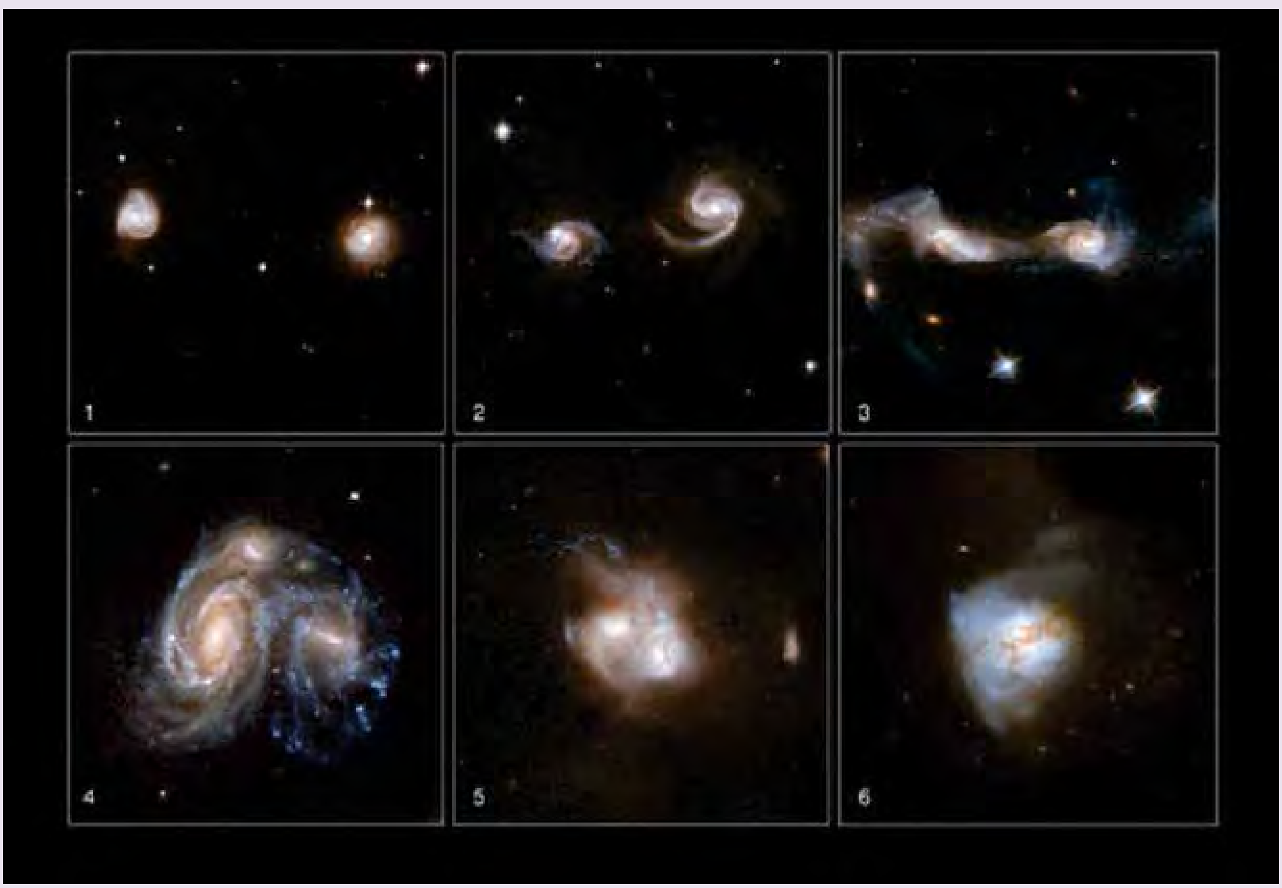
**Box 5:** Each panel here shows two spiral galaxies at a certain stage of their gravitational interaction. The images in the panels are not of the same set of galaxies. The six images have been picked from a larger collection and arranged in this order to give a visual sense of what happens when two galaxies approach each other. One can see that even before merging, the galactic shapes begin to get distorted. This is because of gravitational force, acting over a distance (much like the tidal force). In the last panel, the material belonging to both interacting galaxies merge together into one amorphous galactic structure. With the passage of time, this mass may evolve into a big elliptical galaxy.

Interactions between galaxies, like the one shown here, are slow processes, unfolding over several millions of years. No one is granted that luxury of time to stand and stare. When we survey galaxy clusters at different locations in the universe, we see galaxies at various stages of their merger. Like filling in a jig-saw puzzle, astronomers piece together such bits of information from different parts of the universe to create a working model on how galactic interactions play out in the universe. Astronomers also use the power of supercomputers to artificially recreate galaxy interactions. There are many wonderful animations available online showing galaxy mergers. Here are some examples:

http://hubblesite.org/newscenter/archive/releases/2002/11/video/a/

http://www.ifa.hawaii.edu/~barnes/transform.html

https://www.youtube.com/watch?v=HP3x7TgvgR8 – This last one may be particularly interesting in offering computer visualizations of what could happen during the merger of Milky Way and Andromeda, the big galaxy nearest to us.




made careful observations. From the random motion of galaxies, he calculated an estimate for the total mass contained within the Coma cluster (the so-called **dynamical mass**). To his amazement, the number he came up with was much larger compared to the total mass that one would arrive at by adding up the individual masses of all the stars in all the galaxies that belonged to the cluster (in other words, the mass that was emitting light, the so-called **luminous mass**). The dynamical mass was as much as a factor of 200 more than the luminous mass.

This mismatch left astronomers at a loss. The only way it could be explained was if there was considerable matter within the cluster that was gravitationally interacting with all the galaxies in the cluster. But this extra matter must not be emitting light, and had to be invisible to telescopes, or else we would have found it already. This invisible matter is what is now referred to as 'dark matter'. We now also know that despite moving very fast, galaxies that belong to a cluster remain confined to the cluster only because of the presence of dark matter. The extra gravitational pull of dark matter keeps galaxies from flying apart. This holds true not just for the Coma cluster, but almost every other cluster that astronomers have looked at.

Since Zwicky's pioneering observations, there have been other lines of evidence suggesting that dark matter is ubiquitous. It is the stuff that binds galaxies together, by surrounding them. Careful estimates have also shown that this dark matter far exceeds the amount of ordinary matter that we see in the universe. Thus, whenever we turn our telescopic gaze towards the night sky, we have to remind ourselves that all the illuminated objects that we see are just the tip of the iceberg. In fact, galaxies are like tiny light bulbs hanging on big trees. In darkness, we see the light bulbs, but not the trees.

So what is this dark matter? We do not know the answer to that question yet. Scientists are still speculating on what dark matter could be. It remains one of the biggest unsolved mysteries of modern science. And that's okay, because science is not always about finding quick answers. It is also about searching for new questions. The discovery of dark matter has opened up a lot of questions for which answers are, as it seems, not going to be easy. But scientists are excited because it has fashioned new pathways for research in physics.

What is certain about dark matter is that it cannot be matter made of particles such as protons and neutrons and electrons, the stuff of which you, I, and all the matter that we see around us are made. It has to be something else, a new kind of matter perhaps. Beyond that it remains a mysterious entity, at least for now. But thanks to their gravitational interactions with ordinary matter, we at least know that there is much more to our universe than what meets our eyes.

## References and useful links


1. An interactive tool that explains and demonstrates the formation of tides: http://www.pbs.org/wgbh/nova/earth/what-causes-the-tides.html.
2. An online application that simulates the working principle behind the detection of extra-solar planets: http://astro.unl.edu/naap/esp/detection.html.
3. Galaxy Collider is an interactive tool that allows you to run toy models of galaxy merges with different starting conditions: http://viz.adrian.pw/galaxy/. Clicking and dragging on a blank area starts this simulation. Understanding how this tool works may require a bit of exploring.
4. The Cosmic Cocktail – Three Parts Dark Matter, by Katherine Fresse, Princeton University Press, ISBN 978-0691153353, is a recent popular science book that describes the fascinating story behind the discovery of Dark Matter and the our recent search to understand them.
5. The Crowded Universe, by Alan Boss, Basic Books, ISBN 978-0465009367, is a popular science book on extra-solar planets and the possibility of finding other Earths.



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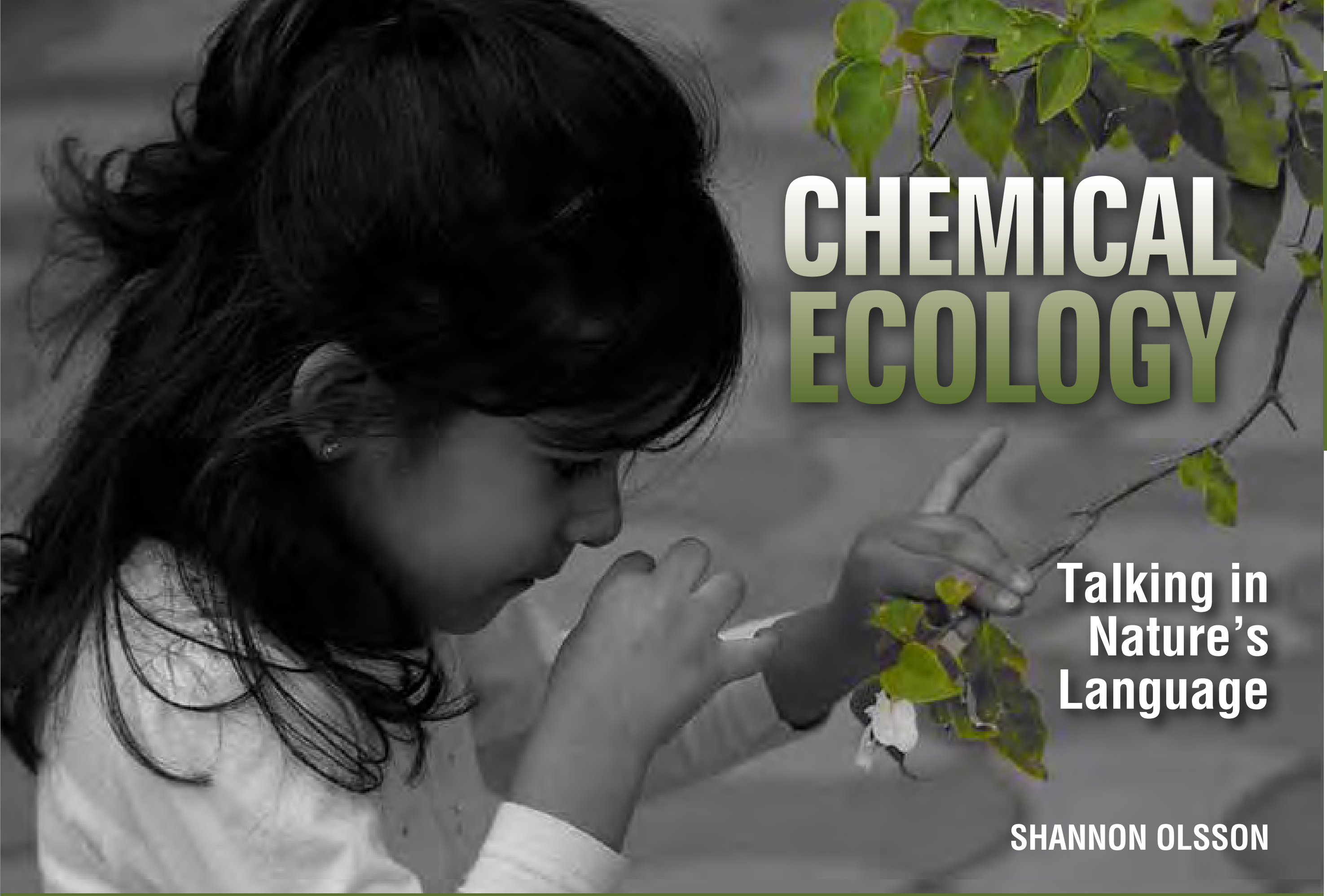

# CHEMICAL ECOLOGY

## Talking in Nature's Language

SHANNON OLSSON

Our planet is made of chemistry. All life, from microbes to plants to animals, uses chemicals to communicate with their world. Chemical cues allow us to communicate with the largest elephants and the smallest bacteria; and can be used to protect crops from pests, identify novel pharmaceuticals, or prevent the spread of disease. In this article, the author examines the role of chemical interactions between living organisms and their environment.

Identifying objects in the world around us is essential for organisms to survive. All living things need to know what to eat, what not to eat, and who might want to eat them. We identify objects using our senses. But what if you couldn't see? Or hear? Or touch? How would you find things in the world around you? And once you found them, how would you know what they are?

This is the dilemma that many organisms face every day. Many insects, for example, can't hear sounds the way we can (they detect vibrations). Bacteria cannot see. And plants can't even move! So how are they able to survive? How can they tell food from poison, or safety from danger?

In fact, there is one sense that is shared by all living organisms. All life, broken down into its fundamental units, is a result of chemistry. Every creature on this planet is essentially a large group of chemicals, all binding and working together. Thus, we all live in a world of molecules. In turn, all organisms can detect chemicals – this is the means by which all life on this planet communicates with each other.

### The language of chemistry

If we could hear the language of chemistry like we hear sounds, our world would be deafening. At any given moment, every leaf, every fungus, every insect, every fish and every mammal is detecting or sending out chemical signals in the environment. To give some examples of the universal language of chemistry, let's discuss some ways organisms use chemicals for survival.

### Finding mates

One of the earliest known experiments to detect chemical communication was performed by Sir John Ray in the 17th Century. Sir John was studying the peppered moth (*Biston betularia*), and noticed that a female moth he had trapped in a cage attracted two male moths who flew in through the window. Since the female could not be seen or heard, Sir John surmised that the males were attracted by the scent of the female. Although he had no way to identify these cues at the time, Sir John was right.

It was not until 1959 that Adolf Butenandt first identified a chemical released by female silk moths to attract males. Chemicals that are used to transmit information between members of the same species became known as pheromones. By 1995, scientists had identified the pheromones used by females of over 1500 species of moths[1]. We also know that females can attract male moths from tens of meters even in dense forest[2]. Today, we also know that animals use pheromones not only to attract mates, but for a range of purposes, like sending out warnings of danger or calling other individuals together.

The *Puccinia* rust fungus uses a different method. In order to reproduce sexually, the fungus must outcross, or fertilize a different population. To do this, the fungus becomes a master of disguise. First, it infects plants and causes them to produce 'pseudo-flowers' that not only look like yellow flowers, but also smell like flowers, and produce a sugary solution somewhat like nectar. Pollinators (such as bees and butterflies) are attracted to these 'flowers', pick up some of the fungus, and transport it to another pseudo-flower, helping the fungus reproduce[3].

### Finding food

Bacteria such as *E. coli* require chemical cues to locate food. Without eyes or ears, their main way of sensing their world is through chemical cues. In the presence of food such as sugars, the bacterium uses its flagellum to swim towards it. It locates the source by swimming in the direction where it senses a greater concentration of sugar. This is functionally similar to how we find a lost cell phone by calling it and going to where the ring tone is loudest. For chemicals, directed movement to higher concentrations is known as 'positive chemotaxis'.

### Teaching Tips

1. For concepts: When you discuss the wonder of chemical ecology with your students, have them taste mustard, cabbage and chili. Ask them what they taste, and ask them if they know what makes up this taste (chemicals). Then, ask students if they can guess why the plant makes these pungent chemicals – you might be surprised what they come up with!
2. For class experiments: Bring several covered jars of spices. Make sure students cannot see the spices. Ask them to open the jars and guess the contents. Then, discuss what it makes them think of – a particular food? A memory?

3. Go outdoors: Take your students outside. Have them observe insects – ants, flies, anything. Talk with them about how these insects might communicate with each other (given their tiny eyes and no ears!). Also talk with them about what kind of information insects might need to know – where is food, where are their mates, where are their enemies, etc. Encourage them to see if they can observe any of these behaviours in action!
4. Individual research: Have students choose a spice. Ask them to research this spice on the Internet to identify what plant the spice comes from, and why the plant produces the compounds we detect in the spice (use mustard and chili as examples).

**Figure 1.** *Puccinia* pseudo-flowers produced on *Arabis*. Source: An Ian Walker photo, uploaded by Lesfreck at English Wikipedia. URL: https://commons.wikimedia.org/wiki/File:Puccinia_on_Arabis.jpg. CC-BY.

For the *Bolas* spider, food is a nice juicy moth. These spiders are named for the sticky ball of silk, called bolas, which they swing into the air to catch a flying insect, much like a cowboy lassoes cattle. Some species even trick their prey with smell. One such spider, *Mastophora hutchinsoni*, adds chemicals to her bolas that mimic the pheromone of several species of female moths. Male moths are attracted by the smell and fly towards the bolas expecting to find a female. Instead they get caught in the sticky ball and become the spider's dinner[4].

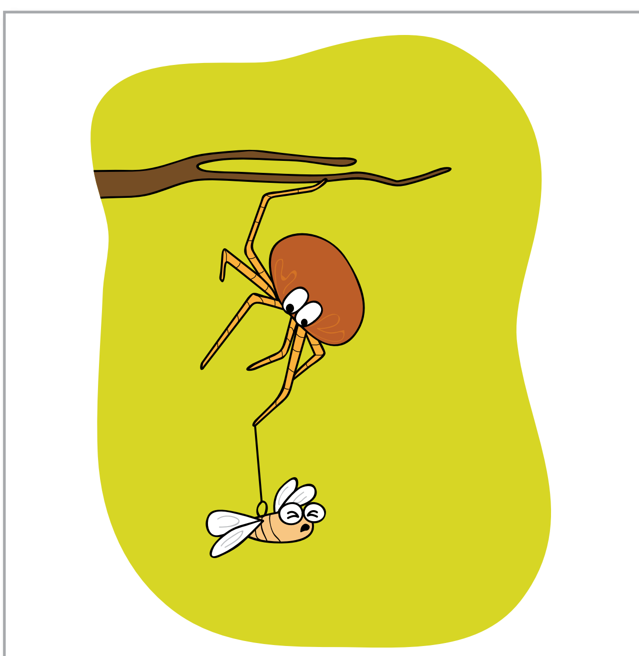

**Figure 2.** Bolas spider lassoing its prey.

## Chemical Ecology

The study of how organisms use chemicals to communicate with their environment is called 'chemical ecology'. Chemical ecology is a relatively new field. The term was first used in the 1960s in the US, although scientists have known that chemicals can be used by organisms to communicate for centuries. Because chemical ecologists can study any living organism, their research can involve nearly every aspect of biology – even medicine. However, the two things that tie all chemical ecologists together are in the name: chemistry and ecology. Ultimately, chemical ecologists are interested in what chemicals are used, and how those chemicals affect the life of the organism. To become a chemical ecologist, a strong background in both chemistry and biology is helpful. But most of all, chemical ecologists must be fascinated by the natural world. Are you interested in animal behaviour? Do you like growing plants? Have you ever wondered why plants make cinnamon, or cloves, or vanilla? Or why we think some smells are bad, and some are good? If so, then you too can become a chemical ecologist!

### Avoiding Enemies

For organisms like plants, that cannot run away, avoiding enemies is a tricky business. Who is a plant's enemy? Generally speaking, it is anything, like insects and microbes that either eat the plant or make it sick. Since they cannot run away, many plants defend themselves by producing toxins or deterrents that can harm or repel their predators. One common example of such a toxin is found in plants like mustard, cabbage and horseradish. The famous pungency you taste when you chew mustard or cabbage is caused by the break-down of chemicals called glucosinolates into isothiocyanates. These pungent isothiocynates are repellent or toxic to many insects and microbes.

Another way plants can avoid enemies is by crying for help. Since they have no way to make sounds, they cry for help with chemicals. When damaged by

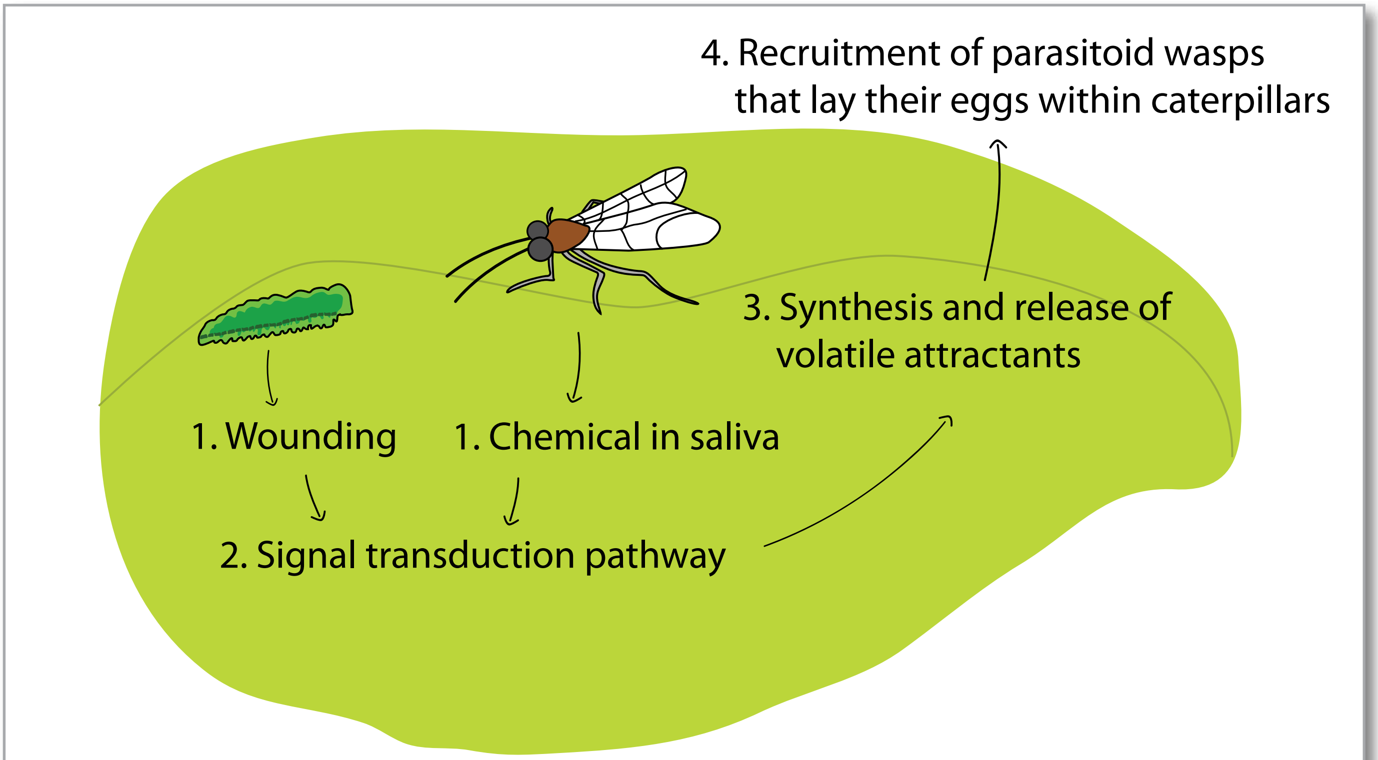


**Figure 3.** A young corn plant uses chemical cues to recruit parasitoid wasps as a defence mechanism against Egyptian armyworms.

insects such as caterpillars, some plants emit certain smells that attract predators of the caterpillar, such as wasps. For example, when the Egyptian armyworm feeds on young corn plants, the plants emit a number of chemicals into the air that attract a wasp that is parasitic on the armyworm[5]. In this manner, the plant calls in reinforcements to take care of the enemy on their behalf. The parasitic wasp, in turn, is able to find its host.

## Chemicals in Action: Some like it hot

If you have ever smelled a fruit to determine if it's ripe, or spat out milk that has gone sour, then you too have used your chemical senses. Humans detect chemicals travelling through the air as smells, and through liquid or solids as tastes. To detect chemicals, we have special proteins in the neurons of our nose or on our tongue called 'receptors' that bind to chemicals and then send a signal through the neurons to our brain.

Although they don't all have noses or even brains, all living organisms - from bacteria to trees - detect chemicals from the environment using such proteins. One amazing example of how plants use these receptors to communicate is the story of the chili pepper. Native to South America, the chili pepper is a staple ingredient in Indian cooking. Indeed, a pinch of chili powder will immediately be met with a sensation of heat. But, have you ever stopped to think why the chili pepper tastes hot?

In fact, chili is actually 'hot', at least to our brains. The heat is due to a single chemical known as capsaicin. This chemical isn't hot by itself, but binds to a special receptor protein in humans known as TRPV1 (Transient Receptor Potential), which is capable of detecting high temperatures. When bound to capsaicin, this protein sends a signal to our brain that says 'Hot!' Interestingly, the same type of temperature receptor in birds does not respond to capsaicin[6]. This means that birds can eat chili peppers without feeling any of the heat. Is there an advantage to having mammals detect the capsaicin, and not birds? Some scientists think so, and they think it might have to do with the role that the pepper serves for the plant.

Chili Peppers are fruits of the chili plant. Like all fruit, they contain seeds. Nice juicy fruit get eaten by animals, who then release the seeds, through their faeces, into the soil where they can grow into new plants. Thus, through its fruit, seeds of the chili are spread far from the parent plants. In 2001, Tewksbury and Nabhan found that when small mammals, such as mice and packrats, were fed chilies (which they would

**Figure 4.** An arrangement of jalapeño, banana, cayenne pepper, chili, and habanero chili peppers – none of which are 'hot' to birds!


eat only if they hadn't tasted them before), the seeds would not germinate (grow into plants). In contrast, when birds were fed chilies, the seeds would grow properly. Moreover, birds were not repelled by the chilies. These scientists proposed that capsaicin might be the chili's way of repelling animals that destroy their seeds (mammals), while animals that can spread their seeds (birds) are not repelled[7].

Tewksbury later found that besides mammals, capsaicin also repelled another unwanted organism that kills seeds – a fungus known as *Fusarium*. Chilies are already known to possess antimicrobial properties, and Tewksbury found that the capsaicin in their fruit protects the seeds from this fungal pathogen[8]. Thus, the hotness of chili protects the precious seeds of the plant from dangers big and small.

## Listening to nature

The chemical language of nature is all around us, but we know very little about what and how organisms on our Earth communicate. Unlocking their molecular conversations can not only help us to learn more about our fellow creatures, but can also reveal new ways to interact with our world. Indeed, the 2015 Nobel Prize was jointly awarded to William C. Campbell, Satoshi Ōmura and Youyou Tu for discovering chemicals that treat diseases caused by roundworm and malaria parasites. These chemicals are natural products produced by bacteria and plants likely for repelling enemies such as microbes. By listening into their conversations, these Nobel Lauriates discovered a new way to treat disease.

Next time you stop to smell a flower, or taste a ripe, juicy mango, I hope you will take a moment to appreciate the amazing chemical language they are using, and try to listen to the sweet story they are telling you.

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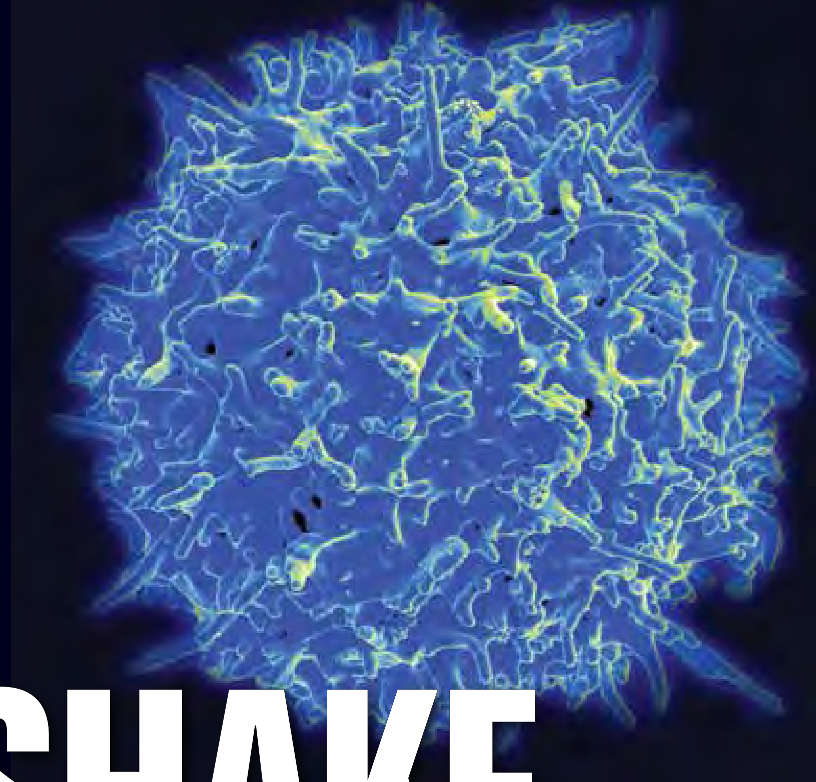
**Shannon Olsson** grew up in the countryside of northern New York State. She was always fascinated by the world around her, and often wondered how organisms in nature were able to live and work together so elegantly. Shannon studied chemistry in college, and in her last year she was able to synthesize a pheromone for the first time. When she saw that something she had created could affect another living organism's behaviour, she became fascinated with chemical ecology. She followed her interests to Sweden, Germany, and is now in India, where she focuses on understanding the chemical ecology of India's immense biodiversity.



# A VIRAL HANDSHAKE

SRIKANTH K.S

We constantly interact with microbes of all sizes and shapes. But, only a very small number of these interactions lead to disease. So, how do disease-causing microbes enter our body? How does the human body defend itself against them? This article explores some of these questions in the context of common cold.

"*I tried to picture myself as a virus or a cancer cell and tried to sense what it would be like.*" Jonas Salk (Scientist and discoverer of the polio vaccine)

What do you do when you meet someone? If you are meeting for the first time, you greet them politely or shake hands with them. If you're meeting a friend, you give them a smile, or greet them with a hug. But what if it's someone you don't like or see as a threat? It's most likely that you'll try to ignore them; under some circumstances, you may even fight with them! We interact with a lot of people – friends, family, people we work/study with - every day of our lives. But did you know that your body is also constantly interacting, in some pretty similar ways, with thousands of living organisms every day? 'How, Where, and Why?' you may ask. To understand, let's take a look at some of these interactions – and what better example can we choose for this than those resulting in the common cold!

Briefly, colds are caused by viruses. If the interactions of the human body with the cold causing virus were to be made into a movie, it would most likely be called 'Cell Wars: Attack of the Cold Virus'. Like any popular movie, this one would also have a Villain (the tiny but cunning cold virus), a Heroine (our body) whom the villain is out to hurt and the Heroes (the small but courageous immune cells).

A virus is a very tiny microorganism that is smaller than a speck of dust! A virus is typically made up of a nucleic acid within a protein coat, and can multiply only within another living cell/ host.

## The cold virus

Allow me to introduce you to the villain of our story - the Virus. Many different viruses can cause colds, but up to 80% of all colds are caused by a viral species, known as Rhinovirus.

> Humans have been getting colds since ancient times. Most adults get colds at least two times a year, while children can get colds 6-12 times a year!

What is a rhinovirus? It is a very small virus, so small in fact that it can only be seen using a very powerful microscope called an Electron Microscope. Its actual size is only 30 nanometers or 0.000003 millimeters (which is almost a billion times smaller than a rhinoceros!). A typical rhinovirus looks very much like a football, with pentagonal parts attached to each other to form a rounded structure. But while a football is smooth on the outside, the outer surface of the rhinovirus (let's just call it the cold virus) is anything but smooth - it's covered with lots of knob-like outgrowths (do remember these knobs, for they play an important role in our story!). There are around 115 different types of rhinoviruses, with very minor differences between them.

Before we go any further, I know what you are impatiently waiting to hear. If it does not look like a Rhinocerous, and is nowhere close to being the same size, why is this cold virus called a rhinovirus? The word 'rhinos' (pronounced rhy-noz) means 'nose' in Greek, which is where this virus likes living. How boring! But at least it will help you remember the name better!

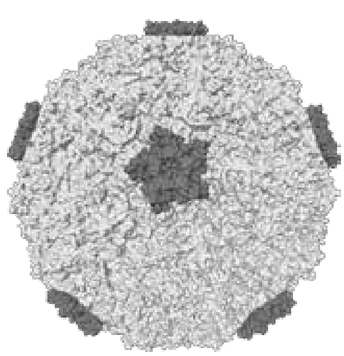


**Figure 1.** A rhinovirus looks like much like a football, except for protein spikes coloured in grey here. Source: Wikimedia Commons. URL: https://upload.wikimedia.org/wikipedia/commons/e/ef/Rhinovirus.PNG. GNU Free Documentation License.


**Figure 2.** The cost of common cold (and influenza). Source: U.S. National Library of Medicine: History of Medicine The Cost Of The Common Cold & Influenza. Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:The_Cost_Of_The_Common_Cold_%26_Influenza.jpg. Image in Public Domain.

Although not a very dangerous microbe, the cold-causing virus is very cunning and so successful that it attacks almost everybody - rich or poor, old or young, male or female - at some point in their lives. Who amongst us doesn't remember the unpleasantness of having a runny nose, sore throat, a feverish body, and in some cases, even the feeling that we may not survive this bout of infection! But don't we almost always recover from the cold, even when we haven't been to a doctor for medicines or had the homemade potion made by our grandmother?!

> Rhinoviruses can infect only humans, gibbons and chimpanzees

How does the cold virus come in contact with your body? The virus can only reach and infect you if you are in close contact with a person already suffering from cold. If we wanted to sound very knowledgeable, we'd call this 'contact transmission'. When a sick person touches an object (like door handle, books, water bottles or clothes), he leaves lakhs of cold viruses on it. Cold viruses can survive (stay alive) for 4-5 hours on contaminated objects (the colder the weather, the longer they live). When an unsuspecting healthy person touches their nose/mouth after shaking hands with a sick person or touching a surface contaminated with the virus, the virus enters this person's naso-pharynx (the cavity in the back of your throat which connects the nose and mouth). In some cases, you can also catch a cold when a sick person coughs or sneezes near you - the virus comes out in small droplets which hang in the air (much like the spray from perfume bottle) and can directly reach your nose. This is called aerosol infection.

> If you (or your friend/family members) are suffering from a cold, then cover your nose and mouth while sneezing or coughing, and wash your hands with soap and water to prevent the virus from spreading.

**Figure 3.** Aerosol infections are caused by the viruses in droplets sneezed out by an infected person. Source: James Gathany - CDC Public Health Image library ID 11162. Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Sneeze#/media/File:Sneeze.JPG. Image in Public Domain

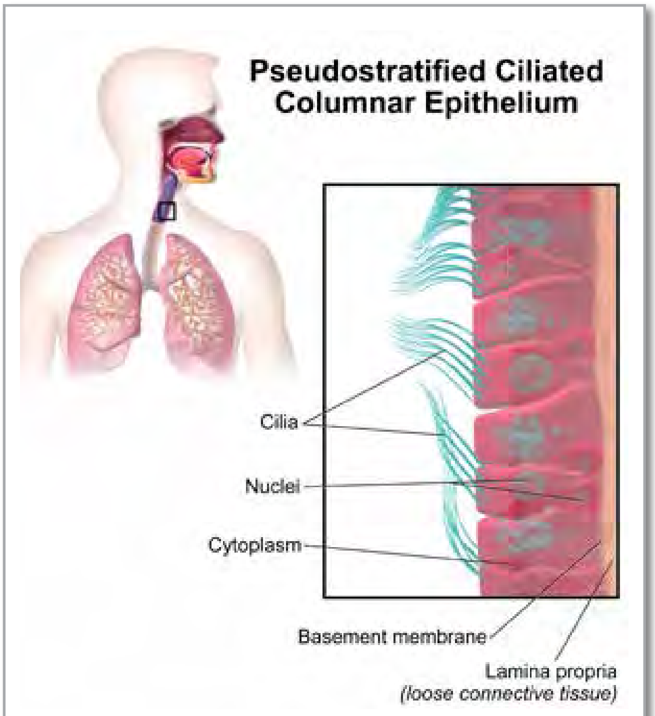



**Figure 4.** Columnar epithelial cells in the mucosa of the wind-pipe. Source: Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762. URL: https://en.wikipedia.org/wiki/File:Blausen_0750_PseudostratifiedCiliatedColumnar.png. CC-BY.

We all know that the air we breathe in through our nostrils reaches the lungs through a hollow tube called the wind-pipe. The wind-pipe consists of four parts – the nasal cavity, pharynx, trachea and bronchi. The entire inner surface of the wind-pipe is lined with a membrane called the mucosa, which is made up of different types of cells arranged in many layers. The outermost layer is made up of epithelial cells (cells arranged in layer to form a tissue which covers the internal organs and the internal surfaces of the body) shaped like columns. Each of these columnar cells has various molecules, also known as receptors, on their surface that are known by exotic names, like ICAM-1 and LDL receptors. As soon as the virus reaches the nose of a healthy person, it starts its dirty work. Remember the knob-like outgrowths on the outer surface of the virus? Well, the virus uses these knob-like appendages (limbs) to hold onto the receptors on

> A receptor is a structure on the surface of the cell (or sometimes within the cell) which can attach or hold on to specific substances or molecules.

> All animals, including humans, reproduce/replicate using DNA (Deoxyribonucleic Acid) as their genetic material. All information, like the colour of our eyes, whether we have straight or curly hair etc., is contained within our DNA, which we get from our parents. In contrast, the genetic material in rhinoviruses is in the form of RNA, which performs roles similar to that of DNA within our body.

the cells of the nasal mucosa. **This is very similar to two people shaking hands when they meet, except that the virus is very rude and does not release the cell's hand!**

Once the virus has attached itself to one of these mucosal cells lining our respiratory tract, it does something very devious. It makes a hole in the wall of the cell and injects its genetic material (in the form of Ribonucleic Acid or RNA) into the cell. This is where the virus shows us that even though it is smaller than even a speck of dust, it is very, very smart. It tricks the cell into thinking that the viral RNA is part of the cell. Unable to see through this illusion, the poor host cell uses its own energy and resources to make hundreds of thousands of copies of the viral RNA. Each one of these RNA molecules, in turn, tricks the cell into making a football-like protein cover with knobs on it. Thus are born lakhs of new viruses. All this is accomplished without the virus spending any energy or resources of its own.

By this time, the host cell has run out of its resources. The newly formed viruses break out from their host cell, killing it in the process, and quickly attack its neighbouring cells, continuing the infection. This is somewhat like a stranger entering your house, fooling you by pretending to be a family member and making you feed him, while he constantly makes copies of himself till you finally starve to death. You can fully appreciate the speed and efficiency of the cold virus when I tell you that one virus can produce lakhs of new viruses within 5-8 hours!

Now that you know how smart rhinoviruses are, and how they attack and kill cells in our body, I can hear you asking me "Why did you tell us that it is not a particularly dangerous microbe? More importantly, how is it that the virus does not kill all the cells in our nasal cavity, and kill us in the process?"

> The thick nasal discharge or phlegm (pronounced flem) that we produce during illness contains cells killed by the virus, and lakhs and lakhs of the virus. The irritation in the throat and nose that are typical of a cold is because of the thousands of mucosal cells that are being killed by the virus, making these areas red and irritable.

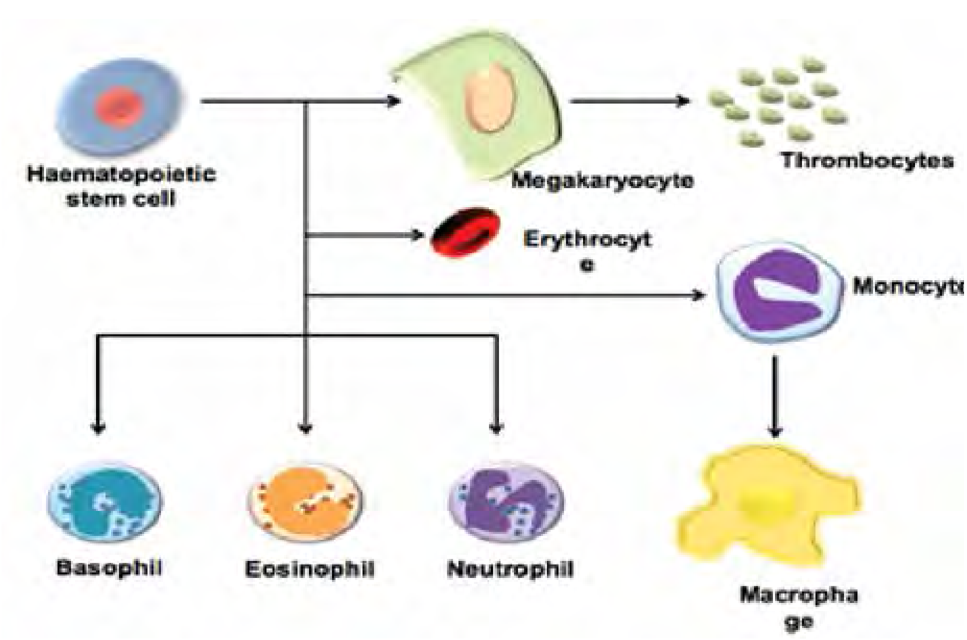



**Figure 5.** The process of haematopoiesis – where the parental haematopoietic stem cells divide and differentiate to give rise to all the other cells found in the blood.

## The immune response

This is where the good guys come in. Ladies and gentlemen, a big round of applause for the courageous defenders of our body! Allow me to introduce the mighty 'Dendritic cell', the majestic 'Macrophage', the hard-working 'B cell' and finally the dependable 'T cell'. Before we get to the climax of our story and the fight between the forces of good and evil, let me quickly tell you about the cells of our immune system.

Our immune system is what protects us against attacks from the hundreds of thousands of microbes, which interact with our body every single minute of our lives. The life story of the cells of the immune system starts inside our bones, in the soft red portion known as the bone marrow. It is here that some very talented cells, called the haematopoietic stem cells, are born. These cells have the capacity to form all the different types of blood cells. Thus, erythrocytes (which carry oxygen and give blood its red colour), lymphocytes (T and B cells), basophils, neutrophils, eosinophils and monocytes (which give rise to macrophages and dendritic cells) are all formed in the bone marrow. From here, they travel in the blood to various parts of the body. Most monocytes, basophils, eosinophils, T cells and B cells stay in the blood, circulating the body continuously in search of invaders. Some monocytes migrate to the skin and mucous membranes of our nasal cavity, oesophagus (food pipe) and intestine, where they change into more mature forms, called dendritic cells. In contrast, monocytes that migrate to organs like the liver and lungs change into the more mature macrophages.

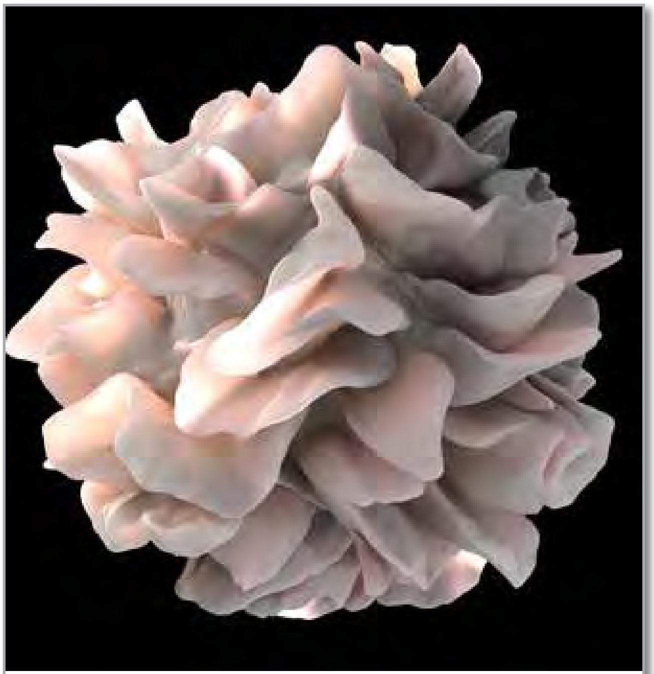


**Figure 6.** An artistic rendering of the surface of a dendritic cell. Source: National Institutes of Health (NIH), Wikimedia Commons. URL: https://upload.wikimedia.org/wikipedia/commons/f/fa/Dendritic_cell_revealed.jpg. Image in Public Domain.

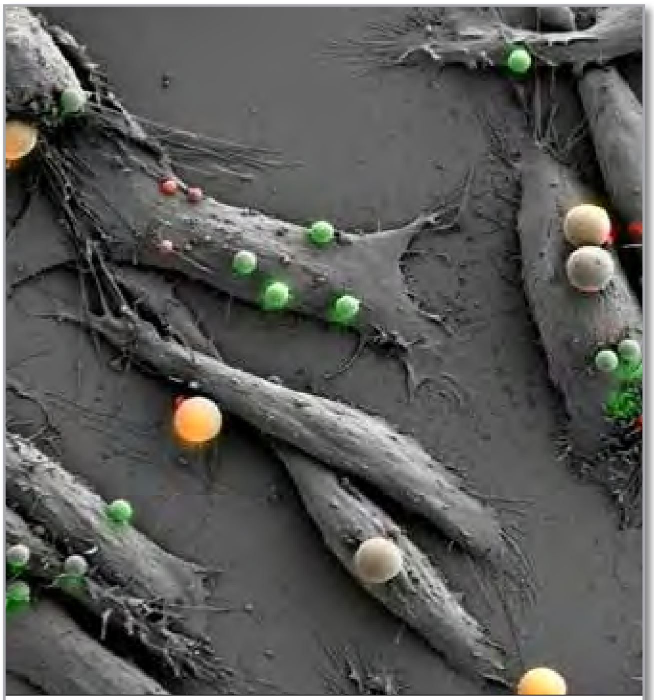


**Figure 7.** Macrophages (with fluorescent beads). Source: Sample by Jeffrey L. Caplan and Kirk J. Czymmek, Bioimaging Center, Delaware Biotechnology Institute. Imaging by ZEISS Microscopy Labs, Munich, Germany. URL: https://c1.staticflickr.com/9/8368/8574591304_66c9ae7e6e_b.jpg. CC-BY-NC-ND.

> Stem cells are master cells in our body. They are capable of dividing throughout our lives, with the ability to grow into many different cell types. They act as the repair system of our body, constantly replacing dead or damaged cells. The haematopoietic stem cell can give rise to any of the different blood cells.

Coming back to our story; when the cold virus first enters our nose and attacks the cells of the nasal mucosa, the attacked cells send out a call for help by releasing chemicals called cytokines. Just like you would find hot samosas by letting your nose guide you to the place where this smell is strongest, the cytokines guide immune cells to the place of attack. The basophils in blood are the first to rush to the area. When the basophils reach the attacked cell, they at once sense the danger and release another very powerful chemical calling for backup forces. This is similar to what happens when a ship sinks in the sea. The sailors at once send out a radio message saying "Mayday, Mayday, Mayday". This is picked up by nearby boats, which rush to the area. On reaching the sinking ship, they help as many people as they can, but also fire bright flares to help rescue planes and ships find other survivors.

The chemical signals are picked up by the dendritic cells and macrophages in the mucosa. These cells immediately swing into action and start attacking the invaders. They not only swallow (eat up) any virus seen outside a host cell, but also swallow some of the infected mucosal cells itself. This process of eating up invaders is called

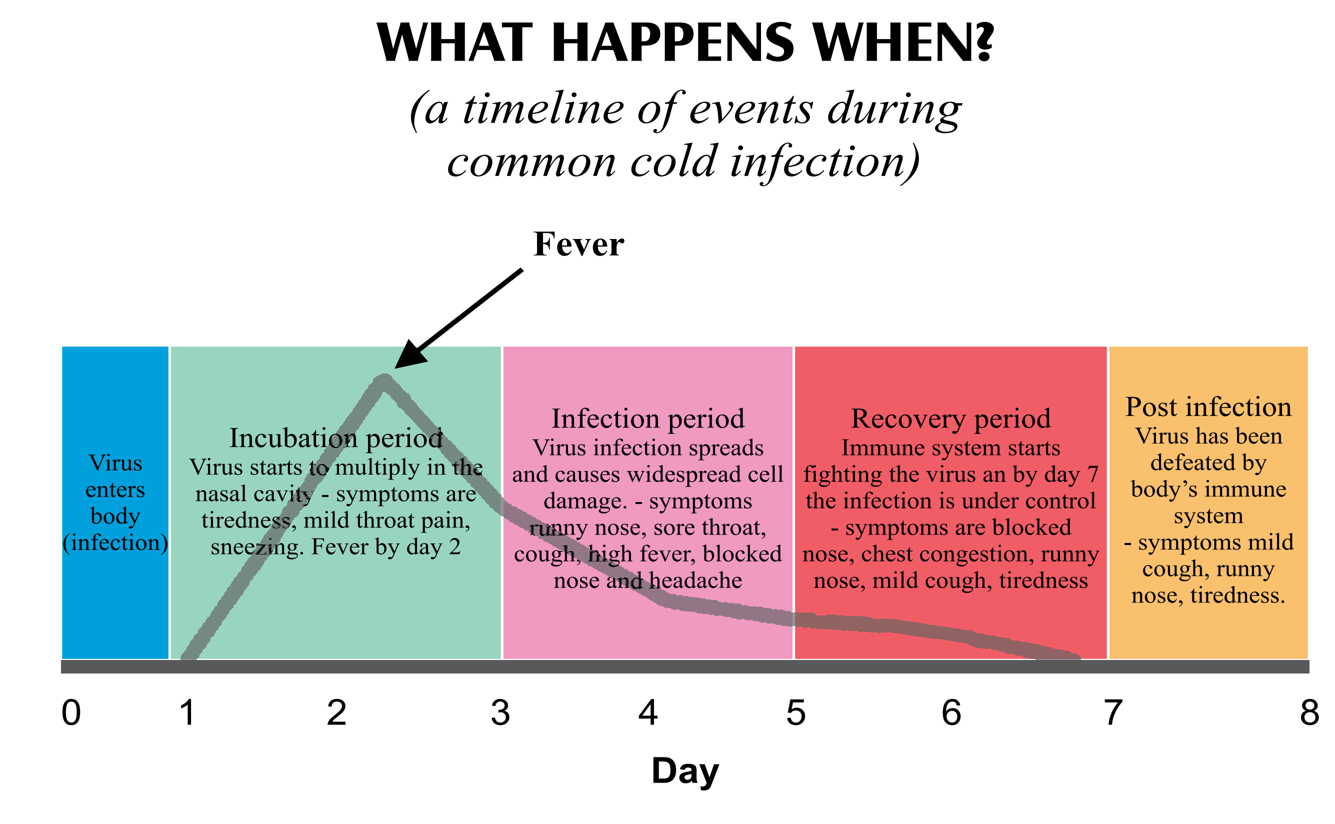



**Figure 8.** A timeline of events.

**Related online resources:**

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Understanding How Your Immune System Works (A Cartoon Story). Retrieved from http://www.healthaliciousness.com/blog/How-Your-Immune-System-Works-A-Cartoon-Story.php

Animation: The Immune Response. Retrieved from http://highered.mheducation.com/sites/0072507470/student_view0/chapter22/animation__the_immune_response.html

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'Phagocytosis' in scientific jargon. Once the virus or infected cell is swallowed, it is chewed up into tiny bits inside special sacs, called lysosomes, containing many enzymes and acids. This is very similar to how the food we eat is digested in our sack-like stomachs. What makes this interesting is the fate of the digested virus. Macrophages and dendritic cells display the chewed up bits of virus like flags on the outer surface of their membranes, almost as if they are saying "I have killed this virus and here is the proof".

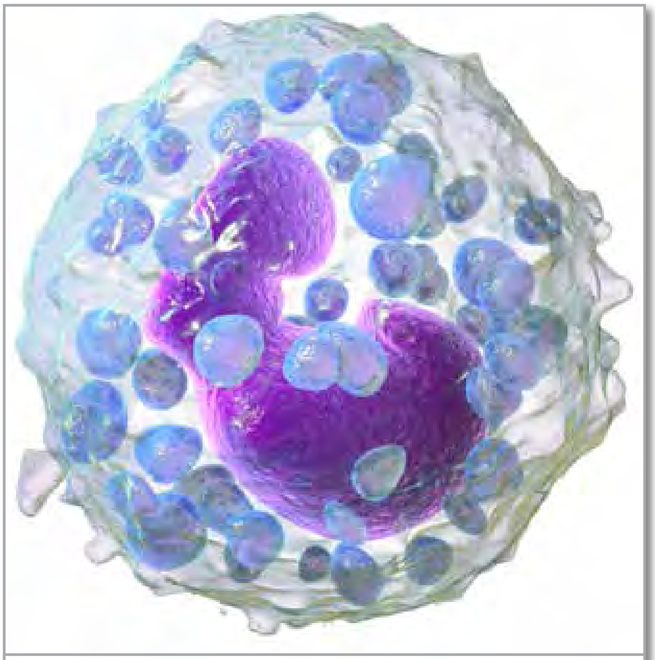

**Figure 9.** A 3-D rendering of a Basophil. Source: Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762. URL: https://upload.wikimedia.org/wikipedia/commons/5/5d/Blausen_0077_Basophil.png. CC-BY-NC-ND.

These flag-carrying macrophages then travel throughout the body till they reach organs like the liver, contacting the lymphocytes (T cells and B cells) along the way. The lymphocytes notice the flags (virus particles) on the surface of the macrophage/dendritic cell. T and B cells have molecules (receptors) on their surface which can recognize and bind to these viral particles only when they are stuck on the macrophage cell surface. It is like when you go to a party and see a stranger there. You do not speak to the stranger till you are introduced to him/her by a mutual friend.

Once introduced to the virus properly, the T cells get 'activated' and are now capable of dealing with the virus themselves (no more introduction necessary). But first they start multiplying very rapidly to produce thousands of 'activated' T cells. To understand this, imagine that you let a guard dog smell a bag of explosives. The guard dog remembers the smell and can sniff these out from anyone anywhere. If the guard dog could also produce many copies of itself, each of which retained this ability to sniff out explosives, they'd be very much like the newly produced copies of activated T cells. These activated T cells are the main

> Some of the activated T and B cells also store a picture of the virus in their database and can live for a very long time. This helps them recognize the same virus the next time it enters the body and they kill it immediately before it has the opportunity to cause the disease. These T and B cells are called 'Memory T and B cells' and they provide our body with long-term immunity to the virus.


**Figure 10.** Poster encouraging citizens to "consult your physician" Source: Federal Art Project, Work Projects Administration Poster Collection (Library of Congress), 1937. URL: https://upload.wikimedia.org/wikipedia/commons/7/73/Pneumonia_strikes_like_a_man_eating_shark.jpg. Image in Public Domain.

army which help defeat the cold virus. They march rapidly to the battle site in the nasal cavity, where they 'sniff out' all the infected human cells, among the many other similar-looking normal body cells. They then attack all these virus-infected cells with powerful chemicals called toxins that kill them before the virus has a chance to multiply inside them. This effectively prevents the virus from multiplying and spreading, thus eliminating the virus from our body. Since these T cells kill infected body cells, they are called 'cytotoxic T cells' (cyto-cell; toxic-poisonous). Some activated T cells help activated B cells produce molecules called antibodies, which can bind to any exposed viruses and help inactivate them. Antibodies stay in our body for a long time and can help prevent attacks by the same virus again, thus protecting us in the future. Once again the forces of good have triumphed over the forces of evil and rid us of a menace, though we are a bit weak from the battle and will need some time to get back our energy and zest for life.

I hope you found that story fun. What? You have another question? Why do we keep catching colds (especially since I've said that we have immunity and memory to protect us)? That is a fantastic question. Remember I told you that there are around 115 types of rhinoviruses. Each time we are infected with a particular type of rhinovirus, we get immunity to ONLY that particular type of virus and not to the others. Also, other viruses like influenza virus, picornavirus (with 99 types), coronavirus and adenovirus can also cause cold, thus making it very difficult for our body to develop immunity against cold.

The next time you catch a cold, Worry Not! Your own private army is alert and will defend you against this menace!

> There is NO known cure against the common cold. Antibiotics (which protect us against bacteria) are of no use against viruses, and only help in protecting us from bacteria which might see our weakened state as an opportunity to attack us. Other medicines, like paracetamol and aspirin, only help in relieving the symptoms. This is the basis of the common saying "An untreated cold lasts for 7 days and a treated cold for a week"!

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# THE FUNDAMENTAL FOUR

SRINIVASAN KRISHNAN

Four fundamental forces in Nature decide all known interactions in the world. What are these four forces? How do they arise? Why four and not more? This article explores some of these questions, describing the properties of the fundamental four and looking at how they shape our daily life.

Forces are all around us. They come in various types and sorts. For example, objects that are thrown up invariably come down due to the force of gravity; there are pushes and pulls that we exert on each other; springs, that operate, say, in vehicle suspensions, which cushion the painful effects of bumps; magnetic forces that appear to act mysteriously to always align the needle of a compass towards the North; forces exerted by hurricanes; the amazingly powerful forces of disintegration unleashed by nuclear bombs and so on. The list is practically endless!

However, there is overwhelming evidence to show that all of these varied forces are, in fact, manifestations of just **four** fundamental forces (although there is enough theoretical evidence to reduce this number to just two, that is a story best left for later). Why just four? The straightforward answer is that this is what we have evidence for. These four fundamental forces in nature are (in order of the strongest to the weakest) called - strong force, electromagnetic force, weak force and gravitational force. We've known of the electric and magnetic forces (now regarded as two aspects of a single force called electromagnetic force), as well as gravitational force from antiquity. In contrast, the other two forces - the strong and weak forces - were only discovered in the previous century. This discovery has dramatically changed the way we look at the world of elementary particles (protons, neutrons, electrons as well as their interactions), and most crucially, our ability to harness nuclear power.

The idea of forces has now been largely replaced by the concept of **fields**. A field is an influence, produced by one or many particles in a certain region of space that can exert a force on other particles. For an example of a field, take a look at the following activity involving magnets.

## Experiment: Magnetic influence at a distance

Take two magnets. Mark their respective North and South poles. Place the magnets on the table with the North poles (or South poles) of both magnets facing each other. Ensure that they are sufficiently far away from each other so that neither moves. Then, begin to move them closer till you begin to feel a palpable repulsion between the two magnets, and they show a tendency to move away from each other on their own. Note this distance down. Repeat this experiment for stronger and weaker magnets. A variation of this experiment can be carried out with opposite poles facing each other (be careful here because the magnets can easily break apart if they are strong enough). In this case, observe how far away the two magnets need to be so that they just begin to move towards each other.

From these experiments, it will become clear that the two magnets can feel each other's presence even without there being any physical contact between them. This non-physical influence of a magnet is what is called its **magnetic field**. Once the first magnet enters the field of the second magnet, it experiences a force (and vice versa). **Seeing** this field is also quite easy. Put the magnet under a stiff piece of paper and sprinkle iron filings on it. The fillings will arrange themselves in patterns that clearly point out the shape of the field in two dimensions. One can play with using two or more magnets and iron filings to get pictures as shown in Figure 1.

One of the most important reasons for replacing the concept of forces with that of fields is that the latter provides a rather elegant way to explain how **quickly** any change in a configuration, say, of masses or charges, can be felt somewhere else. For instance, if the Sun were to disappear suddenly, its gravitational pull on the earth would fall to zero. But we would get to know of it only about 8 minutes later (the time taken for light to travel the distance between the two) and not instantaneously, as this **change** is transmitted through the previously existing gravitational field between the Sun and Earth, at the speed of light.

**Figure 1.** Some pictures of magnetic field lines using iron filings and magnets placed under a sheet of paper. Can you spot opposite poles facing each other above?

## The field of properties and elementary particles

Each of the four forces actually refers to a specific property that particles which produce and are affected by them possess. For instance, gravitational force only acts between particles that have a property called **mass**; electromagnetic force only acts on particles that have **electrical charge**; strong force acts only on particles that have a property that we happen to call **colour** (not to be confused with our usual sense of colour as perceived by our eyes - but those who were doing the naming clearly did not think of interesting enough names) and finally, weak force acts only on particles that have a property that we choose to name as **flavour** (again not to be confused with our usual definition of flavour). These properties are assumed to be independent of each other, i.e., a gravitational field cannot interfere with a colour property, and a magnetic field cannot interfere with the mass possessed by a particle. However, the energy that each type of field can generate can easily be converted from one form to another. For example, gravitational energy can be converted into magnetic energy, or the energy produced by the strong force can be transformed into electrical energy (as in a nuclear reactor) and so on.

Elementary particle physics was born, possibly in 1897, with the discovery of the electron by J. J .Thomson. Then, in 1914, Rutherford experimentally showed that the positive charge (and almost all of the mass) of an atom was concentrated in a tiny core at its centre, called the nucleus. Once the neutron was discovered much later by Chadwick in 1932, the answer to "What was matter made of?" could be answered very simply as "Electrons, protons and neutrons". See Figure 2 for a view of a generic atom.

> For a wonderful introduction to elementary particle, refer:
>
> 1. Particle Data Group of the Lawrence Berkeley National Laboratory (LBNL). URL: http://particleadventure.org/, or,
> 2. CERN outreach site. URL: http://home.cern/students-educators

You might wonder how protons could be lumped together inside the nucleus (with a size of the order of $10^{-15}$ metres) given that they repulsed each other very strongly. Yukawa[1], in 1934, postulated that this was possible because of an exchange interaction of mediator particles called **strong** force as it had to overcome this (Coulomb) repulsion. Similarly, in attempting to explain beta decay in radioactive nuclei, which resulted in the emission of electrons from the nucleus, Fermi postulated another exchange

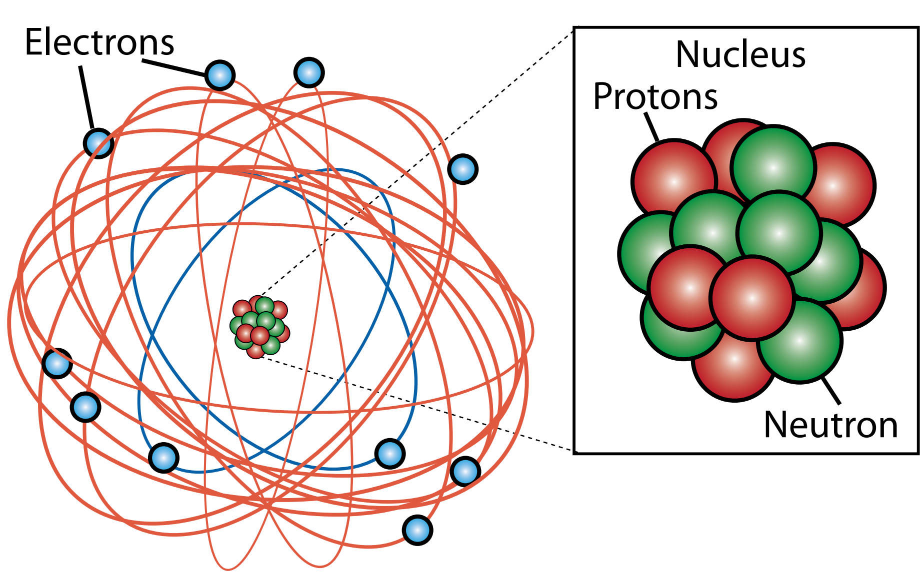



**Figure 2.** A generic atom. Note that the electron orbits are not circular in shape. The nucleus consists of only the protons and neutrons with the electrons orbiting outside. This drawing is not to scale and the orbital shapes are only representative.

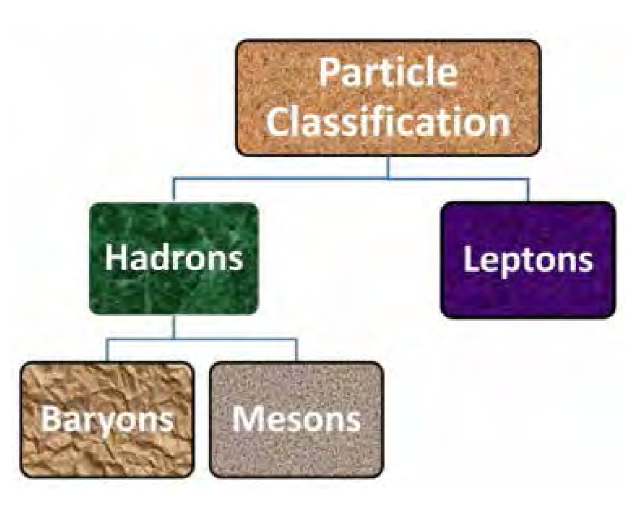



**Figure 3.** Given here is the really simple classification of all the particles (many hundreds have been observed in the lab) known to us. What is remarkable is that all particles fit the above scheme without fail.

interaction over a very short range, also mediated by mediator particles, called **weak** interaction (would you be tempted then to think that electrons exist within the nucleus? This is just not true. No electrons have ever been seen experimentally within the confines of the nucleus and yet they are emitted from there). These Strong and Weak interactions play crucial roles in the (nuclear) reactions that occur in nuclear reactors and in nuclear bombs. In the core of the Sun, for example, these forces facilitate the formation of Helium nuclei out of four Hydrogen nuclei, thereby releasing energy which is crucial to life on Earth. We will look at these exchange interactions in more detail in a later section.

In 1932, the number of elementary particles observed was just three. But by 1960, this number had grown into a veritable jungle. What's more, it was hypothesized that each particle would have a corresponding **antiparticle**. An antiparticle is such that were it to meet its particle, the two would annihilate each other to produce electromagnetic radiation. These were also being discovered experimentally. Thankfully, all these particles could be categorised into three major groups called the Baryons ('heavyweights'), Mesons ('middle weights') and Leptons ('lightweights'). Baryons and Mesons are collectively known as the Hadrons.

Some examples of Baryons include the well-known protons and neutrons and the less-known Lambda, Sigma and Delta particles. Some examples of Mesons include Pions, Kaons, Etas and others. Lastly, some examples of the Leptons include electrons as well as the less familiar muons, tauons, electrons, neutrinos and so on. Do remember that all these particles have their corresponding antiparticles[2].

It was to make sense of all these particles (and anti-particles) as well as the interactions that govern their behaviour, that the **Standard Model** of particle physics was proposed. This model postulates that all the Hadrons are composed of even more fundamental particles, called Quarks, which came in six major types or **flavours**. These flavours were called Up (U), Down (D), Strange (S), Charm (C), Beauty (B) and Truth (T). Each of these flavours of quarks is believed to come in three 'colours', Red, Green and Blue. The anti-quarks are given anti-colours, i.e., anti-Red (also termed minus-Red or Cyan), anti-Green (minus-Green or Magenta) and anti-Blue (minus-Blue or Yellow). In this model, therefore, the total number of quarks (and also that of antiquarks) is 18.

All Baryons are believed to be composed of three quarks bound together. Similarly, anti-Baryons are naturally made up of three anti-quarks. Mesons are believed to be composed of a quark and anti-quark pair bound together. All **observed** particles are thought to have a net 'colour', which is either **white**, i.e., equal amounts of Red, Green and Blue or their anti-colours, or zero where there are equal amounts of the Red and anti-Red, and so on for other colours. Look at Figure 4 for some examples.

Leptons do not have colour. It is because of this that the strong force has no effect on leptons, even though

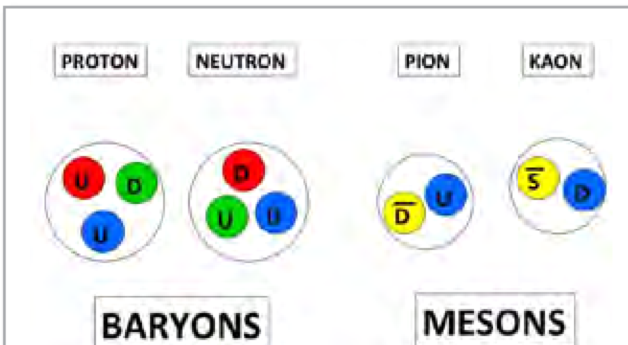



**Figure 4.** The examples above show the composition of some baryons and mesons in terms of quarks. The confining boundary shows that these quarks are actually bound together. The quarks shown here are the U, D and S quarks, and the anti-quarks $\bar{D}$ and $\bar{S}$.

these particles are influenced by weak, gravitational and electromagnetic forces.

Free quarks have **not been observed in nature**. However, experiments have shown that protons and neutrons have a micro-structure composed of three parts, which gives some credence to the quark model. Predictions made using this model have all been experimentally validated, and it is generally accepted that the Standard Model describes elementary particles and their interactions very well.

## The nature of interactions: messengers and fabrics

How do electromagnetic, weak and strong fields arise, and how do they facilitate interactions between particles? It is postulated that every field can be thought to act with the aid of exchanging particles called 'messengers' which carry the force back and forth between two interacting particles. Photons act as messengers for electromagnetic fields by moving back and forth between two charges that are influencing each other (can you see how this picture can be used to explain both attraction and repulsion between charges?). For the strong force, there are eight messenger particles called **gluons**. For the weak force, there are just three messenger particles called **vector bosons**. See the table below for a summary of these messengers.

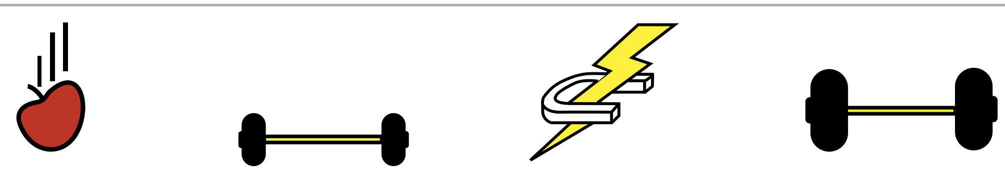
How is the gravitational field described nowadays? Just as for the other three fields, it is postulated that gravity is also carried by a messenger called the Graviton but this has not been discovered yet. However, gravity is really quite different from the other three fields. To see why, let us look at a simple experiment described below.

## Experiment: How does one cancel gravity?

It is amazingly easy. Look at the left panel of Figure 5. It shows a slotted mass hanging from a spring inside a closed bottle. Since gravity is acting on the mass, it is clear that the spring is stretched. When the bottle is now released and allowed to freely fall, the mass moves up and stays there as though the spring was not being stretched at all, till it hits the ground. This shows that there is no force of gravity, **relative to the spring and bottle**, acting on the mass as long as it is falling. So, in general, to cancel gravity on any object relative to its immediate surroundings, one must enable it and its surroundings to enter a state of free fall. This is what happens in space, inside, say, a manned satellite, where the astronaut and the satellite are orbiting the earth, and are therefore in a state of free fall. Hence, the astronaut feels no gravitational force with respect to the satellite and can float about inside it with abandon.

It was based on the result of this experiment, among other things, that Einstein formulated his notion of the General Theory of Relativity. This states that gravity is just a contortion of the **fabric** of space–time by a mass. You can understand this by placing a heavy object like a basketball, say, on a stretched membrane like a trampoline. The trampoline is now deformed or acquires a curvature such that if you roll marbles near it, they will tend to fall towards the basketball in paths other than straight lines. These could either be in the form of curved paths that go around the basketball, or in the form of straight lines.

Carrying this analogy to the solar system and elsewhere, planetary orbits then are just paths that arise due to the curvature of the fabric of space itself by the sun and there is thus no actual force (or field) of gravity present. Gravity can



| | Gravity | Weak (Electroweak) | Electromagnetic | Strong |
|---|---|---|---|---|
| Carried by | Graviton (not yet observed) | $w^+ \; w^- \; z^\circ$ | Photon | Gluon |
| Acts on | All | Quarks & Leptons | Quarks & Charged Leptons & $w^+ \; w^-$ | Quarks & Gluons |

**Table 1.** The second row lists mediators that create the forces that we experience as well as those (that operate at the sub-atomic level) that we don't. Why do we need so many mediators for the strong and weak forces?


**Figure 5. Top panel: Experimental set up. Bottom panel: Actual experiment.** The figures in the left panel show a Mass hanging from a spring inside a bottle that is at rest. The figures in the right panel show the same bottle in free fall – note that the spring is not extended. This shows that the pull of gravity on the Mass is cancelled with respect to the bottle and spring.

be seen, as shown in Figure 6, as a distortion of space–time.

## The nature of the interactions: strength and range

What is the strength of the four fields? How weak or strong are they with respect to each other? Do they vary with distance? Let us rank the four fields in the following way. Imagine that two elementary particles, like protons, were to be placed next to each other. If the strong force acting between them is given a notional value of 1, we will find that the electromagnetic repulsive force has a value of 0.001, i.e., it is one thousand times weaker. The weak force will have a relative value of $10^{-14}$, i.e., it is about hundred trillion times weaker. Finally, the gravitational force between the two protons will have

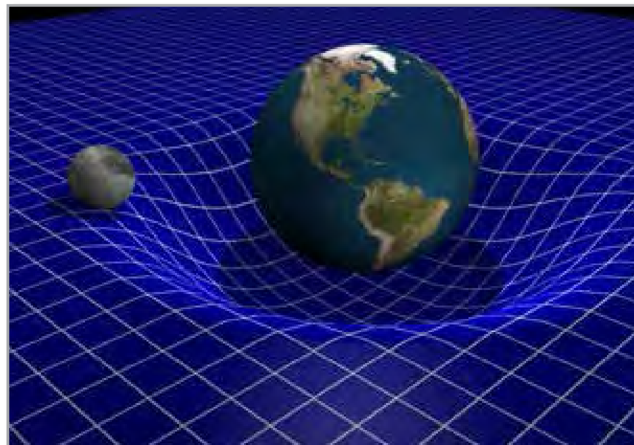


**Figure 6.** Gravity is a distortion of space-time which is depicted here as a coordinated system (look at the grid lines). It is this coordinate system that is distorted by the mass of the planet
Source: This has been taken from https://i.ytimg.com/vi/cxgHz5H4AHA/maxresdefault.jpg and https://www.youtube.com/watch?v=cxgHz5H4AHA.

a relative value of $10^{-43}$, i.e., it is ten tredecillion times weaker!

The electromagnetic force is probably the most significant force in our lives. This is primarily because the electrons, which orbit the nucleus, repel each other. This in turn implies that two atoms which try to come too close simply cannot do so. All the properties of matter, which produce the pushes and pulls that are most familiar to us, arise primarily from this effect between atoms. Since it dwarfs the gravitational effect by a factor of $10^{40}$, it follows that we need a huge mass like the earth, which is also largely charge neutral, to produce a strong enough Gravitational pull to keep us down. Look at Figure 7 for a comparison between the electrical and gravitational force.

Both gravitational and electromagnetic fields have a range that is infinite. There is no way to escape these forces by moving away from them. It just becomes weaker the farther away you go, but can never become zero (one can, of course, cancel the force out at specific points but that is a different thing since one needs to use other masses or charges to do so). The strong and weak fields, in contrast, have a very short range, which acts only across distances typically the size of the nucleus, about $10^{-15}$ metres. Beyond this distance, they fall to zero. So for either of these two forces to come into effect, elementary particles must be forced to interact at very short distances. Since atoms cannot come that close to each other under ordinary circumstances of temperature and pressure, we cannot experience these forces in a direct way.

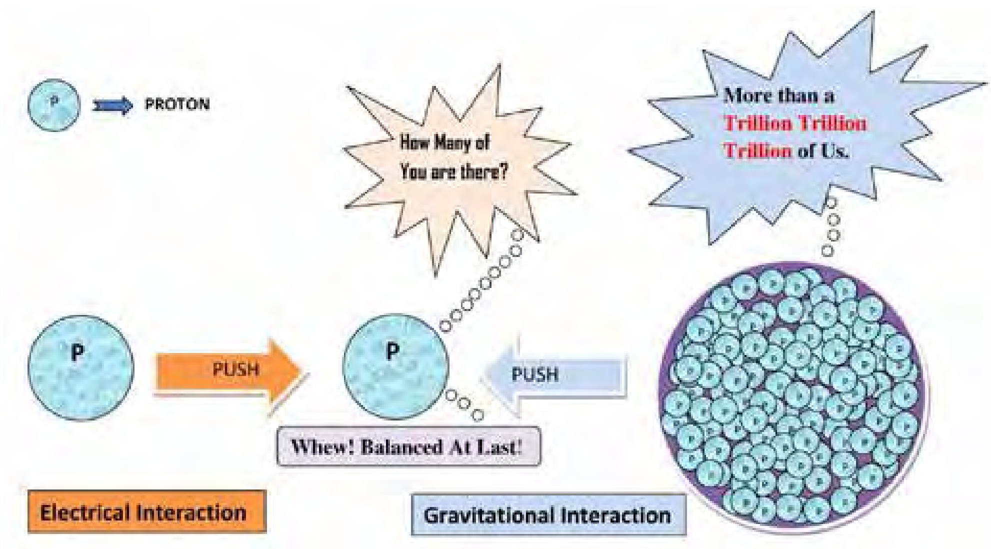



**Figure 7.** Comparing electrical and gravitational forces. The proton in the middle has no net force on it. On the left, it is being pushed by another proton using only the electrical Force. On the right, it is being pushed by a bunch of protons using only the gravitational Force. To balance the two forces, and provide the required gravitational force strength, the number of protons one needs on the right is more than 1.25 Trillion Trillion Trillion, i.e., 1.25 ×1036 protons.

To summarise, one sees that the electromagnetic field largely determines the size and composition of planets. Even commonplace technologies rely on this field. The strong and weak forces power the stars by enabling nuclear fusion at very high temperatures within their cores. They also power nuclear bombs and nuclear power plants. The gravitational force produces all the most important known structures, like stars, galaxies, galaxy clusters, etc. in the observable universe. These structures have stupendous quantities of largely charge-neutral matter present in them. Gravitational fields are also directly responsible for producing the most energetic events in the universe, like gamma ray bursts, supernovae and so on. This is because a large enough amount of matter can exert a force much stronger than the other three forces, and can paradoxically set into motion tremendous quantities of energy. There is something significant after all in being heavy enough.

## Conclusion

These four fundamental interactions between particles have been sufficient to describe most of the observed properties of matter, but it is not impossible that some other forces can occupy such a fundamental position in the future. For example, recent cosmological evidence shows that 96% of the known universe may contain both a different sort of matter and energy called dark matter and dark energy respectively. It is speculated that dark matter has an attractive gravitational force, and dark energy has what looks like a repulsive gravitational force. They are termed dark because unlike ordinary matter, they do not absorb and emit electromagnetic waves. Knowledge of these forces may very well unlock many more kinds of fields. There appear to be surprises galore just waiting to be explored!

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# MATERIAL INTERACTIONS

YASMIN JAYATHIRTHA

Why can't you make pots with garden soil? Are you doomed to have straight hair all your life? What is artificial silk? Find out the answers here.

Interactions between four fundamental forces are known to describe the physical universe. Of these, physicists attribute interactions between atoms to the action of electromagnetic forces. Chemists, on the other hand, think of these same electron–nucleus interactions in terms of many other forces, depending on the strength and arrangement of the bonds they form. Thus, in chemistry, it is the combination of these subtler forces that shapes the properties of materials. These interactive forces allows us to understand why there are so many different kinds materials, all with different properties, and undergoing so many reactions, that allow all life, including us, to eat, grow and reproduce. They enable chemists to not only explain why a diamond is one of the hardest substances on Earth, but also to make other materials that are equally hard.

What are these chemical interactions that shape our material world? While, many of these interactions are strong and directed, and are called bonds; there are others that are simply referred to as non-bonded interactions. Let us take a look at some of these interactions, exploring how a combination of forces can explain the properties of substances, both natural and human-made. **The description given here is necessarily very simple and any high school or college text will give more details.**

## Covalent bonding

Electrons are attracted by nuclei. When two atoms come together, the nucleus of each attracts the electrons of the other, and so the atoms are stuck together or bonded. When the two atoms are identical, as in $H_2$, the electrons are shared equally and the

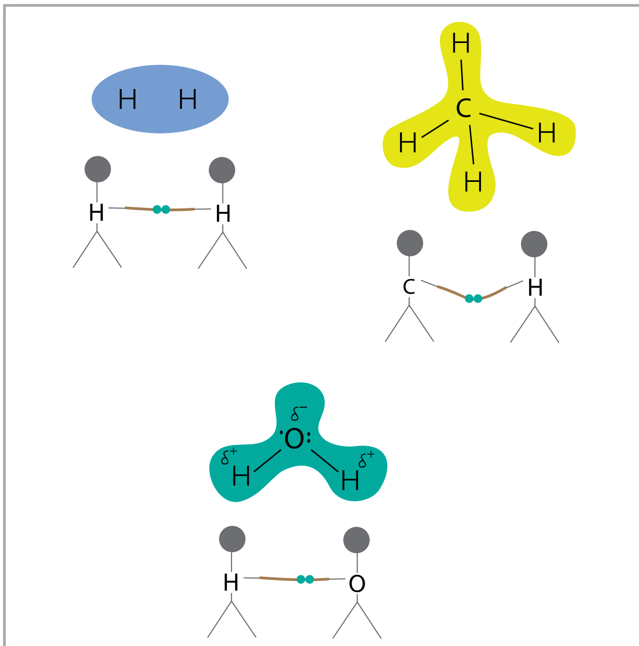



**Figure 1.** Structures showing dipoles formed by unequal sharing of electrons.

bond is called non-polar (refer Fig. 1a). This can also happen when the atoms are not identical but have the same pulling power as each other, as in $CH_4$ (refer Fig. 1b). When the atom of one element has a greater attraction for electrons, it can pull the shared pair of electrons toward itself, making a polar covalent bond, as in $H_2O$ (refer Fig. 1c). These bonds are arranged so that the electron clouds are as far away from each other as possible. This leads to different geometries in molecules, as we will find out when considering different substances (refer Fig. 2). When the difference in pulling power is very large, one atom can pull away the shared electron completely, becoming negatively

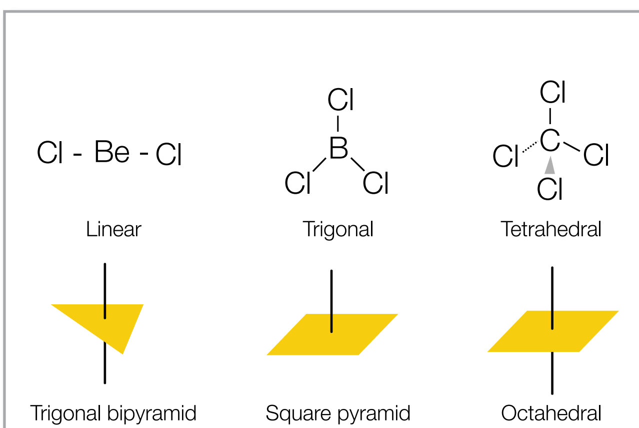



**Figure 2.** Shapes molecules adopt when there are different numbers of electron pairs.

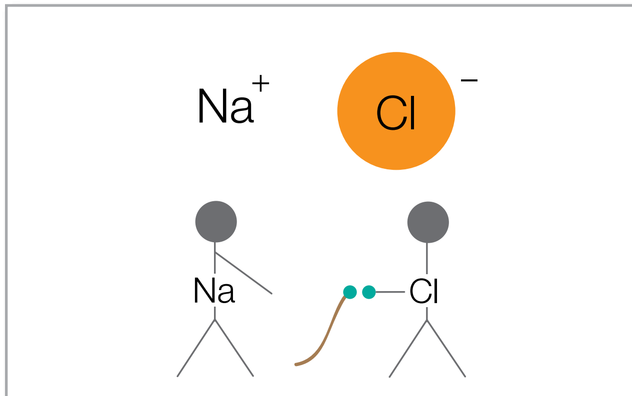



**Figure 3.** Formation of Sodium Chloride.

charged, an **anion**. The other atom has one less electron, is positively charged, and is called a **cation** (refer Fig. 3).

## Ionic bonding

Ionic lattices are formed when the positive charge on a cation attracts negatively charged ions around itself and vice versa (refer Fig. 4). How ions arrange themselves in this lattice depends on their charge and size, but they are held together by a strong attraction. In ionic compounds, i.e., those made up of only ions, the strength of these interactions determine a variety of physical properties, such as melting points and solubility in water.

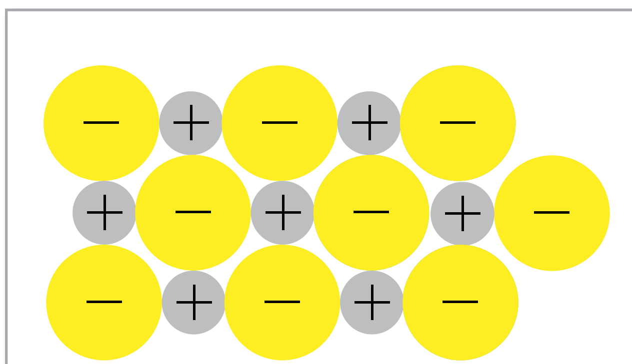


**Figure 4.** Arrangement of Na+ Cl- ions in sodium chloride crystals.

## Metallic bonding

Elements that hold their electrons very loosely form metallic bonds. A metal consists of an array of positive ions surrounded by a 'sea' of electrons (refer Fig. 5). Since these electrons are loosely held, they can move and rearrange themselves, making the metals they are part of capable of conducting electricity, and also malleable and ductile (refer Fig. 6).

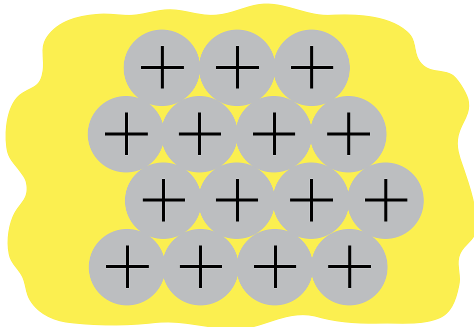


**Figure 5.** Metallic bonding.

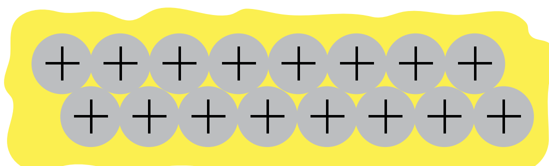


**Figure 6.** Metal after hammering.

## Non-bonded interactions

If bonds were the only interactions between particles, all substances would be either solids or gases! Atoms/ ions forming a large array, held together by covalent, ionic or metallic bonds, would be solid at room temperature. Alternatively, atoms in small molecules like methane or water would be gases - with no forces holding these molecules together, they would be free to move away from each other. But water is a liquid at room temperature. What forces hold the water molecules together such that they are free to move but not escape from each other? These forces, collectively called non-bonded interactions, are of several kinds.

How do non-bonded interactions arise? Any atom or molecule has a cloud of electron charge around it, which fluctuates, creating a momentary dipole in the molecule. This dipole can induce a dipole on a neighbouring molecule, causing the two molecules to stick together for a brief period of time (refer Fig. 7). This force is called **instantaneous dipole-induced dipole** interaction, or dispersion force, and is very weak. However, the more electrons there are in a molecule, the stronger these forces are, especially when they act cumulatively (with energies <10kJ/mol.).

The second kind of non-bonded interaction is that of **dipole–dipole** interactions, shown by those molecules that have polar bonds. In a molecule that contains atoms with different electro-negativities, charges within molecules are polarised to form a dipole. The positive end of one molecule attracts the negative end of another molecule, causing them to cluster together (refer Fig. 8).

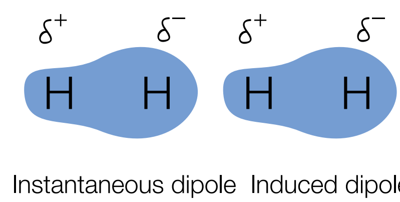



**Figure 7.** A fluctuation on the electron cloud of one molecule 'instantaneous dipole' causes a distortion on the neighbouring molecule 'induced dipole' leading to dispersion forces.

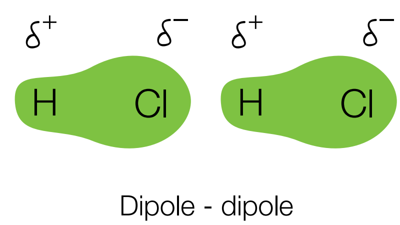



**Figure 8.** Attraction between opposite charges of two molecules causes them to stick together.

**Box 1:** The weakest interactions between particles (atoms and molecules) are called dispersion forces and require very little force to overcome them. But they exist between all substances and lots and lots of them can do wonders!

The house lizard, the gecko, can usually run upside down on a ceiling and hang there without falling. It seems to overcome the force of gravity for long periods of time, but can still unstick itself when it needs to run to catch an insect. Scientists, including Aristotle in the 4th century BCE, have long wondered how the gecko manages this feat. Turns out, geckos have special pads on their feet that, under greater magnification, are found to be made up of many (~500,000/foot) bristles. The ends of the bristles are further split into 100-1000 mini bristles, called spatulas, which make contact with surfaces like walls. It is through these numerous contact points, and the non-bonded force of attraction between them, that a gecko overcomes the force of gravity without using any energy or muscle power. In fact, as scientists who studied this found, even a dead gecko could stay stuck on the ceiling.

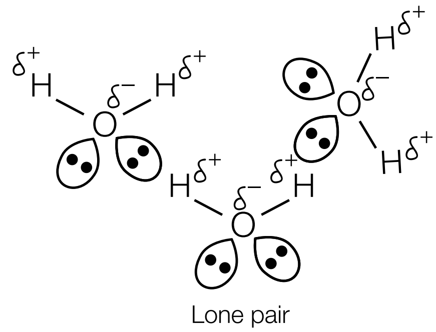



**Figure 9.** The positive charge on the hydrogen atom attracts the electron cloud of the oxygen lone pair, forming a hydrogen bond.

The third important non-bonded interactions are those mediated by **hydrogen bonds**. Hydrogen bonds are very special bonds, formed by molecules that have hydrogen bonded to a highly electronegative element such as fluorine, oxygen or nitrogen. These elements pull electrons away from the hydrogen atom, forming a polar bond. Because the hydrogen atom is very small, it can polarise the electrons on the neighbouring F, O or N atom forming a weak bond ~ 10-40 kJ/mol. (refer Fig. 9). Covalent bonds have energies between ~ 450-200 kJ/mol. Although hydrogen bonds are much weaker, they are strong enough to not only hold molecules together but also change their physicochemical properties. For example, the properties of water are largely ascribed to the hydrogen bonding between oxygen of one molecule and hydrogen of another molecule. Thus, hydrogen bonds play a very important role in all biological molecules, systems and processes.

**Box 2: Hydrogen bonds**
Many of us have had difficulty ironing creased cotton clothes. Cotton is made of cellulose, a polymer of glucose, and can form hydrogen bonds between strands, holding them together. It is very hard to iron out a crease, when a cotton cloth is dry; but when water is sprinkled on the cloth, the hydrogen bonds within the crease break, and are re-formed with water instead. Iron off the water, and the crease is gone. This is very similar to the way you can curl or straighten your hair after dampening it, but a humid day or a wetting will reverse the style.

Why are these bonded and non-bonded interactions that operate in the materials we see around us important? Let's start by looking at the earth beneath our feet, the structure of the soil minerals and their properties.

## How many ways can silica bond?

The basic component of soil is silica: $SiO_2$, in a giant covalent lattice, called quartz; where each silicon atom is covalently bonded to four oxygen atoms and each oxygen atom is bonded to two silicon atoms. Quartz gets weathered or broken down by the action of wind and water into smaller pieces or sand. When these react with water, they result in the formation of silicate ions or $SiO_4^{4-}$ that look like a tetrahedron (refer Fig. 10). Many of the earth's minerals are silicates that are linked together in different ways, through shared oxygen atoms, forming single or double stranded chains (refer Fig. 11a and 11b). Thus, for example, asbestos (refer Fig 12a) is made up of double stranded chains and peels off in strands; while mica (refer Fig12b) is made up of sheets (refer Fig. 12c) of the tetrahedra. The negative charge on silicate minerals is balanced by positive ions, like $K^+$, $Mg^{2+}$, $Ca^{2+}$ and $Al^{3+}$, held by ionic interactions. As weathering continues, $Al^{3+}$ replaces some of the silicon in the layers, converting sand into clay. The minerals in clay consist of two kinds of sheets held in layers - tetrahedral sheets mainly consisting of silicate tetrahedral; and octahedral sheets consisting of mainly of $Al^{3+}$ surrounded by six $OH^-$ ions (refer Fig. 13).

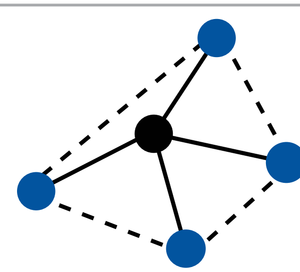


**Figure 10.** Silicon tetrahedron.

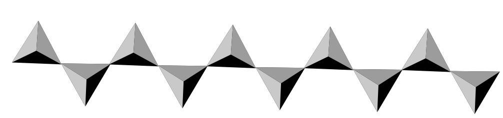


**Figure 11a.** Silicate Single strand.

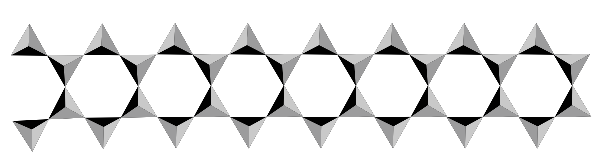


**Figure 11b.** Silicate double strand.

**Figure 12a.** Asbestos: fibres made of double stranded silicate chains. Source: Nikhil Fernandes.

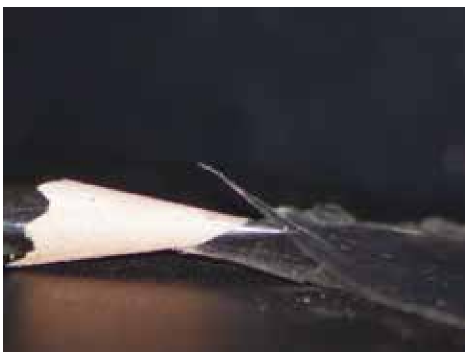


**Figure 12b.** Mica: made of sheets of silica tetrahedra. Source: Nikhil Fernandes.

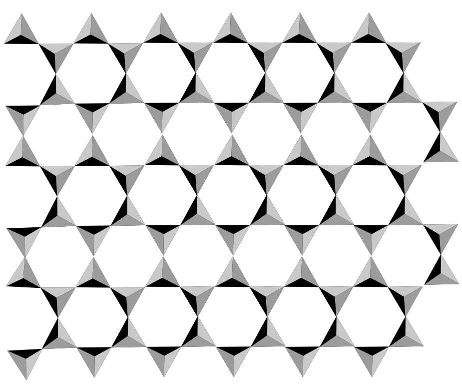


**Figure 12c.** Silicate sheet

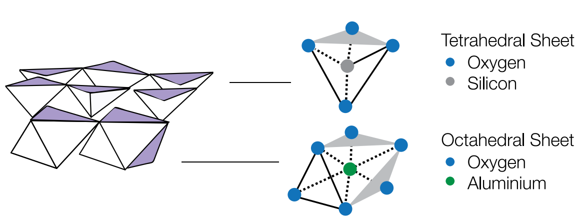



**Figure 13.** Layers of tetrahedral and octahedral sheets held together by shared oxygen atoms.

Different types of clay have these layers arranged differently. Kaolinite, which is the clay used for making pots (refer Fig 14a), has a 1:1 structure - one tetrahedral sheet bonded to one octahedral sheet. These layers are held together tightly by hydrogen bonds between the OH of the octahedral sheet and the O of the tetrahedral sheet (refer Fig. 14b). These prevent water and cations from entering between the sheets and, therefore, do not allow the clay to expand very much. The small amount of water that does enter the clay, and rests between its crystals, allows it to be moulded into different shapes that hold (refer Fig 14c).

**Figure 14a.** Kaolinite clay can be made more pliable by wedging, where it is rolled into a tight spiral with a sort of kneading method, which removes air pockets. Source: Lalita Manjunath.

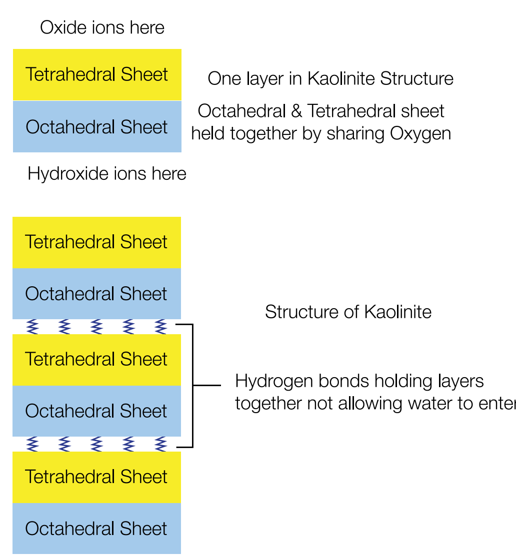



**Figure 14b.** The structure of Kaolinite shows tightly held layers, giving it characteristic modelling properties.

**Figure 14c.** The small amount of water that enters clay allows it to be moulded into pots. Source: Lalita Manjunath.

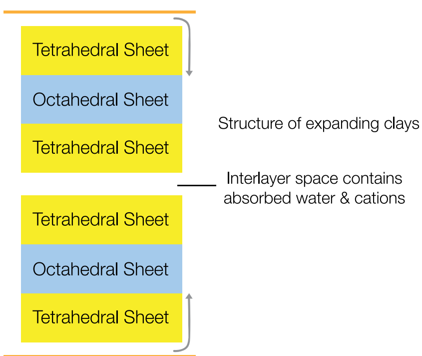



**Figure 15.** The structure of expanding clays – the lack of hydrogen bonds between layers allows water and ions to enter.

On firing the clay, this water is eliminated, but the layers are now held together by covalent bonds. These bonds are strong enough to prevent the clay from being recycled, and thus the moulded clay holds its shape permanently (refer Fig. 15).

Other clays that make up soil are 2:1 clays, where an octahedral sheet is sandwiched between two tetrahedral sheets. The tetrahedral sheets in these clays cannot bond together, but being negatively charged on the surface, allow water molecules and cations to move in between them, allowing these clays expand. These clays are like store-houses for plants, providing plant roots with water and minerals (refer Fig. 16).

## Molecules of life

Nothing shows the role of these various interactions better than the structure of proteins. Proteins are polymers or long-chain molecules that are made up of

**Figure 16.** Soils containing expanding 2:1 clays crack and shrink when dry. Source: jackmac34, Pixabay. License: Public Domain. URL: https://pixabay.com/en/drought-earth-desert-aridity-711651/

smaller molecules, called amino acids, held together by covalent bonds. There are 21 such amino acids which combine in different ways to form proteins with diverse properties and functions.

This diversity can be seen by taking just two examples of proteins in the human body. One, called amylase, is a protein that is water-soluble and catalyses the digestion of starch; while another, called keratin, is tough, inert, water insoluble and forms the hair on our heads.

**Activity - Hydrogen bonds and Disulfide Bridges in the Kitchen.**

We 'see' hydrogen bonds forming and breaking when we iron out creases in damp cotton clothes. But another place to notice this is in making 'atta' for chapattis. Once I realised that this is what was happening, I notice it every time with interest!

Take flour in a vessel and run your fingers through it to get a feel of its temperature. Add water, again dropping it over your fingers. As you mix the flour and water together, the mix will feel perceptibly warmer. This is because energy is being released as the water forms hydrogen bonds with the –OH groups in starch.

Take a piece of this mixture and hold it under running water. It will wash away. Continue kneading and the dough will become elastic. Two types of proteins - gliadins and glutenins combine together to form gluten. This is a water-insoluble protein mass, held together by disulfide bridges, mostly made by the kneading action and the incorporation of air. If you now take a lump of atta and wash it under running water, the starch will wash away leaving behind the elastic gluten lump.

Proteins have complex structures that are assembled in three (or four) layers. The first, called a protein's primary structure, is the sequence of its amino acids held together by covalent bonds. This linear chain coils into sections of helices and sheets, held together by hydrogen bonds (refer Fig. 17). This is called its secondary structure. In its tertiary structure, protein molecules fold into various shapes using non-bonded interactions, ionic interactions, and a very special covalent bond called the disulfide bridge (refer Fig. 18). Consider milk. The proteins in milk are held in solution and will not settle down on keeping. Curdling the milk to make paneer breaks the tertiary and secondary structures of its proteins, precipitating them out. This happens because adding lemon juice or vinegar disrupts the ionic interactions and the hydrogen bonds within proteins, which can no longer interact with the water in milk in the way they originally did. When we eat paneer, digestive enzymes of our gastro-intestinal tract break the covalent bonds holding the primary structure of amino acids together.

It is these intricacies of folding that make amylase a compact molecule that can be held in solutions (like our saliva), while exposing a region that can accommodate its substrate starch molecules. If we change the secondary structure of amylase by heating or changing the pH of its environment, the amylase will not catalyse the reaction any more.

In contrast, the tertiary structure of keratin is made up of secondary structures of helices winding around each other, and held together by disulfide bridges. The number of these disulfide bridges in keratin varies from one individual to the other; and in general, the more their number, the curlier is one's hair! By dampening your hair and combing it out in the style you want, you can temporarily straighten curly hair or curl straight hair. By the time your hair dries, new

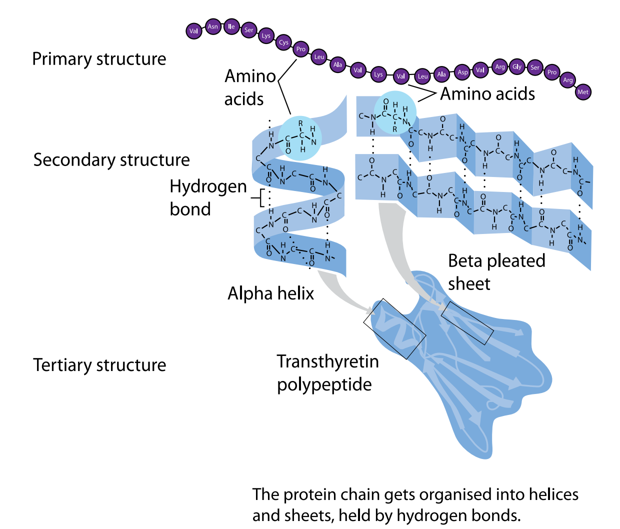



**Figure 17.** Levels of protein structure.

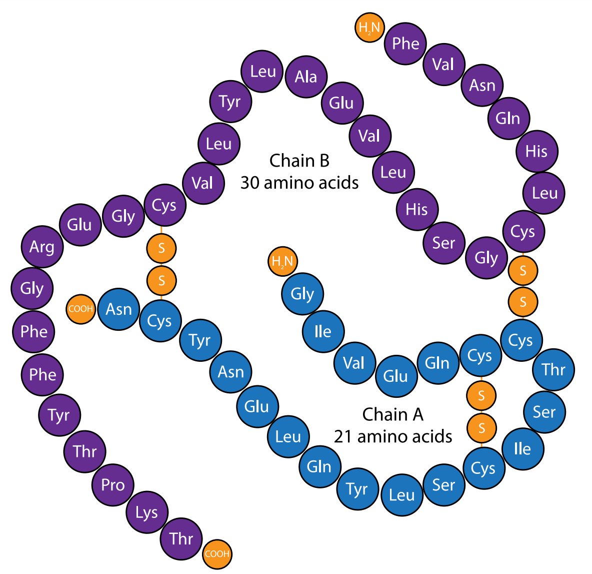



**Figure 18.** Disulfide bridges bring together different parts of a protein chain, giving rise to specific shapes.

One among the many interactions that hold the structure of a protein together is the disulfide bridge. The amino acid cysteine contains the –SH group. Two –SH groups can link together and get oxidised to form –S-S-, the disulfide bridge. This brings different parts of the protein strands together, giving a specific shape to the protein. Hair contains a lot of cysteine - the number of disulphide bridges a strand forms decides whether your hair is curly, wavy or straight. While you can temporarily change your hairstyle by putting rollers on damp hair, a more permanent change will require a change in its existing disulfide bridges. To do this, a reagent called ammonium thioglycolate, containing a –SH group, is applied to hair to break its existing disulfide bridges. This allows you to set your hair in a style of your choice. Once new bridges are formed by oxidation, the reagent is washed off. Your hair is now the way you want it! Of course, when new hair grows, it will be what it was before you styled it - unfortunately, you cannot change your genes.

hydrogen bonds are formed within the keratin, which will persist (and allow you to retain your new hair style), till your hair is dampened again, or the air gets damp. To get a more lasting 'perm', the disulfide bridges within hair have to be broken using sulfur compounds, and reformed in the required style. While this perm stays permanently, as your hair grows, it comes out in the way it is naturally.

## Designer molecules

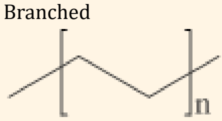
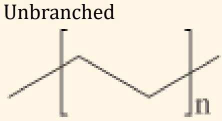
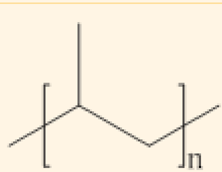
As if the variety and number of proteins in the natural world are not mind-boggling enough, we are now able to synthesize many artificial polymers with exactly the properties we want.

The first plastics were formed by accident. We are all familiar with polythene, PVC, Teflon and polystyrene (popularly known as Thermocole). While all of them have different properties and uses, their basic structure is the same with only their side-chains being different (refer Table 1). In poly-ethene and poly-propene, the main forces of attraction are non-bonded interactions between the long chains. So these plastics are soft, soften with heat, and are mainly used for plastic bags. In contrast to low-density polythene (LDPE), with its loosely packed branched chains, synthetic high-density polythene (HDPE) has more compactly packed side-chains, giving it higher melting points and making it stronger. The side-chains of PVC or polyvinyl chloride are held together by strong polar bonds, making PVC harder. Similarly, the strong covalent carbon fluorine bonds in Teflon (poly-tetra-fluoroethene) make it quite inert. Since fluorine holds its electrons quite tightly, the dispersion forces in Teflon are weak, giving it its ability to act as a non-stick coating in cookware.

How can one change the properties of a polymer? Broadly, there are three ways of doing this:

- By changing its side chains – more polar side-chains bring greater interactivity.
- By changing the length of the chain – longer chains have stronger intermolecular forces.
- By changing the orientation of the side groups – helping the chains pack better.

A polymer similar in structure to polythene is poly-ethenol. Polyethenol has many hydroxyl (–OH) groups in its side chain. When 99-100% of the polymer is made up of –OH groups, it becomes insoluble, with hydrogen bonds forming between the side-chains. As the percentage of –OH group's drops, the polymer becomes soluble in water, since the gaps between its side-chains allow water molecules to penetrate and react with the polymer. Making use of this property, poly-ethenol is used to make hospital laundry bags. When infected clothing is put into these bags and

| POLYMER | COMMON NAME | STRUCTURE | FORCES BETWEEN CHAINS | PROPERTIES | USES |
|---|---|---|---|---|---|
| **Polyethene Low Density** | Polythene LDPE | Branched  | Dispersion forces | Inert, softens with heat, can be moulded | Plastic bags, wrapping |
| **Polyethene HDPE** | Polythene HDPE | Unbranched  | Dispersion forces. Chains pack closer | Softens at higher temperature than LDPE. Inert | Bottles, Pipes, Lab beakers etc. |
| **Polypropene** | Poly-propylene |  | Dispersion forces. | Higher softening point since forces are larger. Inert | Furniture, pipes, Lab equipment that can be sterilised. Hinges for pop up lids |

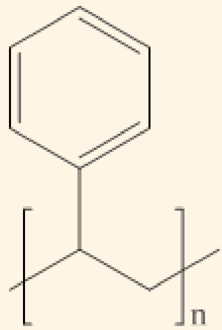
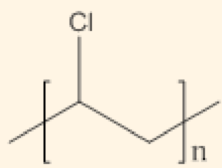
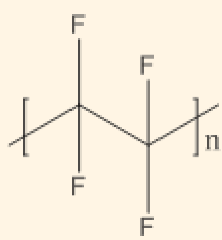
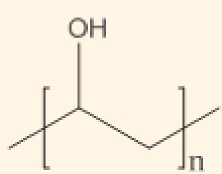
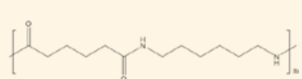
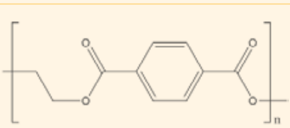
| POLYMER | COMMON NAME | STRUCTURE | FORCES BETWEEN CHAINS | PROPERTIES | USES |
|---|---|---|---|---|---|
| **Polystyrene Hard and foam** | Thermo-cole, Styrofoam |  | Dispersion forces | Hard, and tough, can be formed into a lightweight foam | Packing material, insulation, lab equipment |
| **Polychloroethene** | Poly vinyl chloride PVC |  | Dipole-induced dipole | Hard and strong | Pipes, wire coatings |
| **Polytetrafluroethene PTFE** | Teflon |  | Dipole- dipole between chains | Inert, High melting, non-stick since electrons are held tightly by fluorine so does not interact with other molecules* | Coatings for pans, valves, lubricant |
| **Polyethenol** | PVOH |  | Hydrogen bonding | Depends on % of –OH groups: >99% insoluble in water, 99-90% soluble in hot/ warm water. < 90% soluble in cold water | Hospital laundry bags. Surgical stitches |
| **Polyamides** | Nylon |  | Hydrogen bonding | Strong, high melting, resistant to decay, can be moulded | Clothes, ropes Machine parts |
| **Polyetheleneterephthalate Polyesters** | Terylene, PET, |  | Hydrogen bonding | Strong, high melting | Clothes, films (Mylar), bottles |

**Table 1.** Polymers are long chain molecules with differing side groups. Interactions between the chains increase with size and with the structure, changing the properties. *Since fluorine holds on to its electrons very tightly, dipoles don't get induced very readily, so dispersion forces are weak. Even a gecko will not stick to Teflon.

loaded into washing machines, the bags will dissolve, releasing clean clothes.

Chemists have also tried to mimic natural polymers like silk, wool and rubber. Silk and wool are made up of proteins, and nylons and polyesters are their equivalent synthetic versions. These synthetic polymers can be drawn into fibres, and woven into cloth. These properties are partly due to the chemical nature of the molecule, and partly due to the way it is processed.

Similarly, chemists have played around with molecules to get Kevlar (strong and lightweight), PHA (fire resistant) and polycarbonates (replacement for glass).

## Conclusion

We live in an age where we can design new materials using our knowledge of molecular interactions. Many recent efforts in this field, for example, are aimed at making bio- and photo-degradable synthetic polymers.

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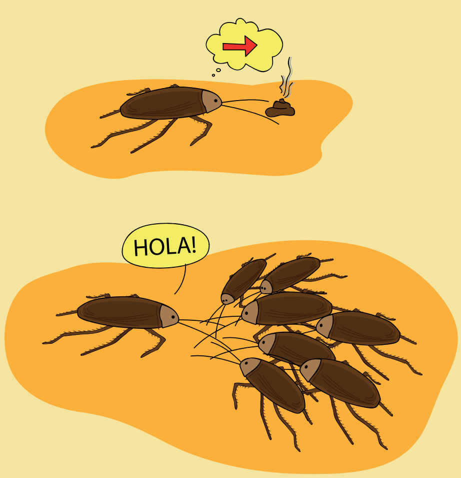
# Poop Helps Insects Socialise

***– Vignesh Narayan***

"Man is a social animal" said Aristotle, the philosopher who lived 2300 years ago. What he did not know, and what scientists today have found out is that insects too are social animals. This is why if you find one cockroach in your house, chances are that there are a hundred more hidden from view. What has puzzled entomologists (people who study insects) is how these insects communicate with each other.




Cockroach biologists (yes, there are some!) have come up with the answer. Cockroaches, they say, are attracted to poop. Apparently, the tendency of cockroaches to aggregate together is because of their attraction to volatile fatty acids that bacteria present in the faeces produce. When cockroaches were hatched and raised in germ-free cages, they turned out to be very solitary folks, hardly even stopping to rub antennae. These socially awkward cockroaches regained their camaraderie and group clustering when the bacteria were re-introduced into their cages.

In fact, other insects also communicate by using bacteria that give off certain odours and chemicals. Locusts play host to a specific kind of microbe that helps them aggregate and form a swarm. Some animals too, like the hyena, have bacteria in their scent glands which help them tell relatives from non-relatives.

So next time you're looking for someone in a crowded room, close your eyes and give the air a good sniff!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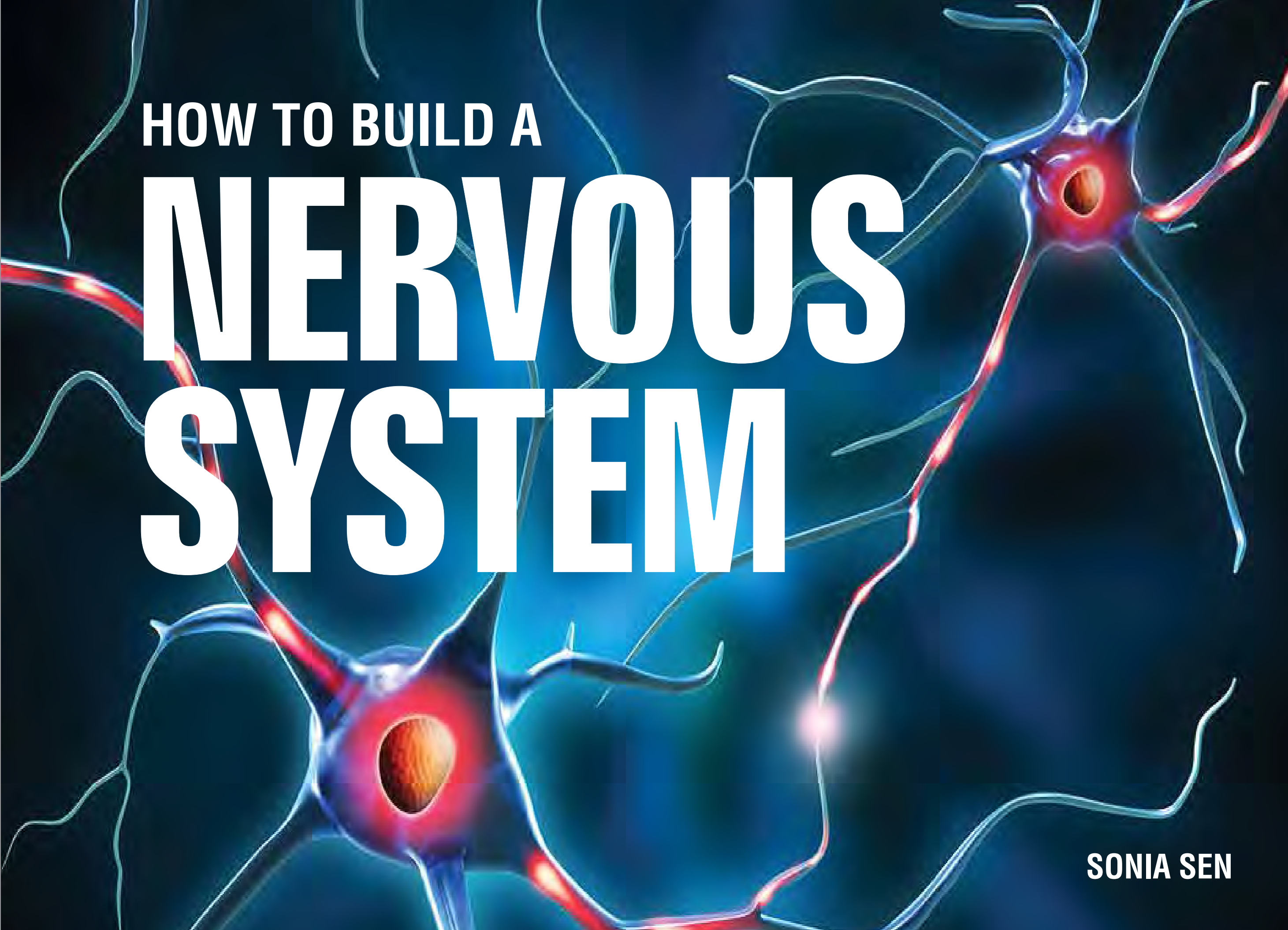

# HOW TO BUILD A NERVOUS SYSTEM

SONIA SEN

Animals constantly interact with their environment for the most vital of functions - finding food, avoiding predators or courting a prospective mate. What role does our nervous system play in these interactions? What do we know about this vital organ system and how it is made?

Some of the most exciting things about animals are their intriguing behaviours. Ants trailing behind each other, kingfishers diving to catch fish, lizards dropping their tails, cuckoos chasing crows, octopuses changing their colour and shape, spiders building webs, even people on the train holding their nose as it goes past a sugar factory… all these are examples of the fascinating things animals do to find food, avoid anything that is noxious, escape predators, attract mates, or rear their young.

Despite their apparent complexity, each of these behaviours involves three steps:

1. Sense the environment: Animals survey their environment through various 'sensory stimuli' such as light (through vision), sound (through hearing), volatile and non-volatile chemicals (through smelling and tasting) and pressure (through touch).
2. Process the sensory information: Once animals receive sensory information, they need to process it to make a decision about it – does the environment pose a threat, an opportunity for food, or a possible mate?
3. Produce a response: Once a decision is made, animals need to produce an appropriate behavioural response to the stimulus – avoid it, eat it, or mate with it!

These interactions between animals and their environment are mediated by the nervous system.

## What is the nervous system?

Most multicellular animals, from jellyfish to human beings, possess some sort of a nervous system. While some of these are relatively simple, others are infinitely more complex. Despite these differences in complexity, their nervous systems are made up of essentially the same kinds of cells, and operate in similar manner.

Nervous systems act as communication networks within organisms. This 'network' is made up of special cells called neurons that are intricately connected to each other. Neurons have the unique ability to receive chemical information from one end, convert it into an electrical signal so that it passes very quickly through to its other end, and then convert it back to a chemical signal that the next neuron can pick up. This form of chemical communication between two neurons happens at junctions called 'synapses'. This ability of neurons to transmit information rapidly is what allows you to quickly withdraw your arm when you touch a tumbler of hot coffee: the sensory neurons in your hand sense the heat, quickly relay this information to interneurons, which tell the muscles in your arm to contract (outlined in Fig. 1).

Have you noticed that this is like a simple electrical circuit? And while this is the simplest possible circuit, for a very simple behaviour, involving just three neurons, other circuits can involve many, many more neurons. Such circuits are often also intricately interconnected, giving circuit diagrams of even the simplest nervous systems a gargantuan complexity. Something else you might have noticed even in this very simple circuit is that all three neurons look very different from each other. This is another striking feature of nervous systems – neurons can be of the most diverse and beautiful shapes and types!

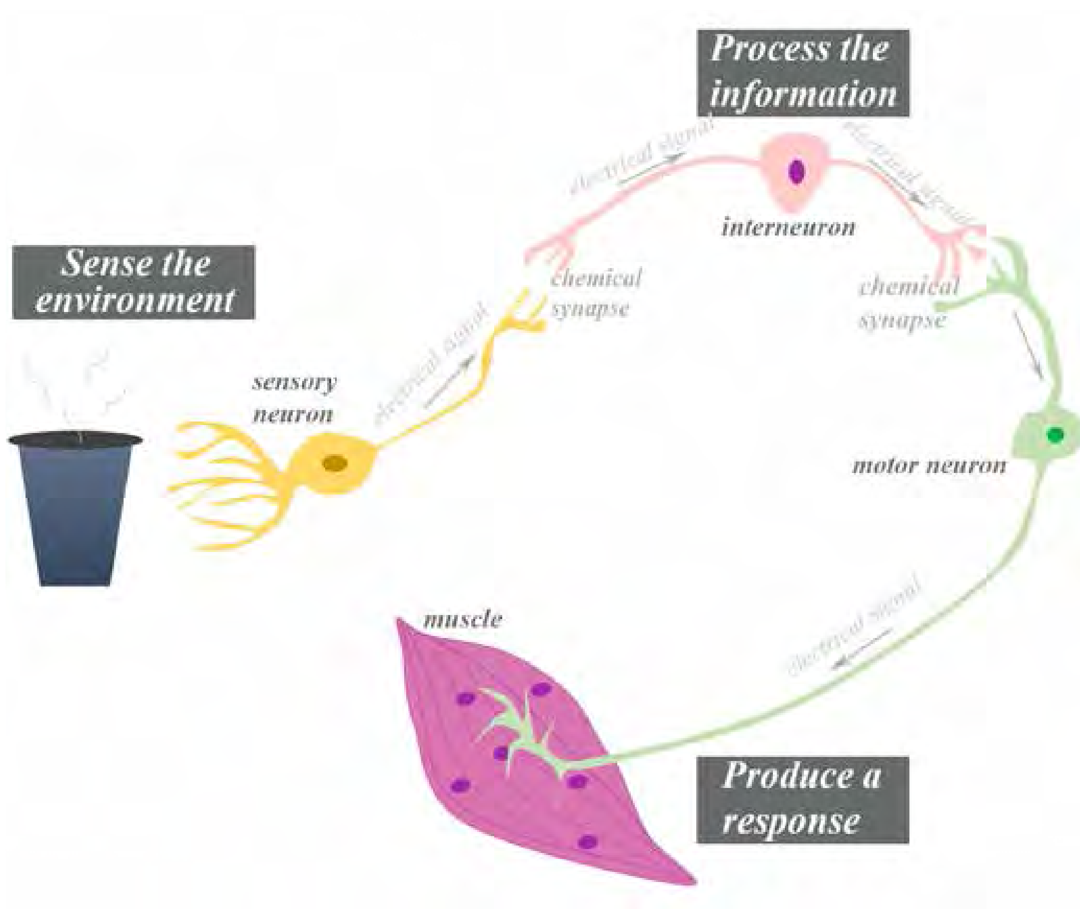


**Figure 1. Animals interact with their environment through the nervous system.** Sensory neurons in your fingers sense the heat of the coffee tumbler. They quickly relay this information to your spinal cord, where it is processed, and onto an interneuron, which in turn activates a motor neuron in the muscles of your arms, telling them to contract. Notice that all the communication between neurons happens at the synapses, through chemicals called 'neurotransmitters'. These chemicals can either activate or shut down other neurons. The chemical information a neuron receives is converted into an electrical signal so that information from one end of the neuron is transmitted rapidly to the other end. In this way, through a three-neuron circuit, you are able to retract your hand very quickly from a hot coffee tumbler.

It's easy to see why over the centuries, scientists have been fascinated by nervous systems. How do neurons talk to each other? What are the circuits for different behaviours? How are these circuits built? How are memories stored in them? …The questions are innumerable! Countless people have worked on them and we have learned some extremely fascinating things!

## Many ways of studying nervous systems

Scientists have used many approaches to study the nervous system. Studying the 'giant' neuron of squids, we have learnt how proteins control ion exchange across the cell membranes of neurons and how this allows neurons to generate the electrical pulses with which they transmit information rapidly[1]. Scientists have also tried to build circuit diagrams of entire nervous systems by tracing how individual neurons are connected to each other. As a result, we know the circuit diagram for the entire nervous system of the worm, *Caenorhabditis elegans*[2] and of the maggot[3] (the larval stage of the fruit fly, *Drosophila melanogaster*), each of which has 302 and 10,000 neurons respectively. Extensive studies are now underway to do this for parts of the mouse and human brains as well[4]. These studies will undoubtedly be more challenging to reconstruct given that mice have about 70 million neurons and humans have about 80 billion!

Within such complete circuit diagrams, scientists have also tried to trace 'sub-circuits' that are actually functionally important – for example, the three neuron circuits involving the hot coffee tumbler is a functional circuit. More complicated behaviours have more complicated circuits, and scientists use electrical probes inside individual neurons to painstakingly trace out entire functional circuits. One of the first few such studies led to a beautiful illustration of the entire circuit that controls the swimming behaviour of leeches[5]. This may appear mundane, but in reality, it represents a huge leap in our ability to work out the neural wiring circuits that underlie complex behaviours. With new technologies, we can now not only watch neurons when they are active, but also shut down or activate them individually merely by shining light on them or by a small change in the temperature[6,7]! This allows us to trace out more complicated functional circuits in complex nervous systems and, therefore, to understand and compare how animals recognise odours, process visual information, taste, fly, walk and even integrate these complex behaviours!

## Fruit flies show us how to build a brain

Another approach has been to understand how these complicated circuits are built so that no wiring mistakes are made. In a previous example, the fact that everyone on a train smelled the volatiles from the sugar factory, recognised it as malodourous, and brought their hands up to hold their noses at roughly the same time means that all of them possess the same functional circuit for this sequence of events. That the neurons in one person are connected up in exactly the same way as they are in another means that there must be rules that allow such a complex circuitry to be built repeatedly in every person. What are the rules that instruct the formation of the nervous system and its complicated circuitry?

Over the last couple of decades, we have gained considerable knowledge about this process. This understanding comes not from studies in human beings, but from studying other animals such as mice, fish, fruit flies and worms. Though there are large differences in the nervous systems of these animals and the way they develop, there are many common principles that have emerged. In contrast to its insignificant size and less than flattering reputation in kitchens across the world, the contribution of the humble fruit fly to this understanding has been extraordinary!

With about 100,000 neurons, the nervous system of adult flies is rather complex. At first glance, its structure and the complicated connectivity seem devoid of any rules that could govern its construction. But research has shown that there **are** rules and some very simple ones too! So how does its egg, which is a single cell, go on to generate 100,000 neurons of different shapes and types, and how are they connected up correctly?

### Making neural stem cells

To deal with this problem, the fly embryo first makes stem cells. Stem cells are a neat trick used in almost all tissues of nearly all developing embryos to increase the number and types of cells that can be produced. This is because when a stem cell divides into two, one of the cells becomes a specialised cell and the other is a copy of itself. This allows the stem cell to generate many specialised cells, while continuously replenishing its own numbers. The stem cells that make the nervous system in the fly embryo are called

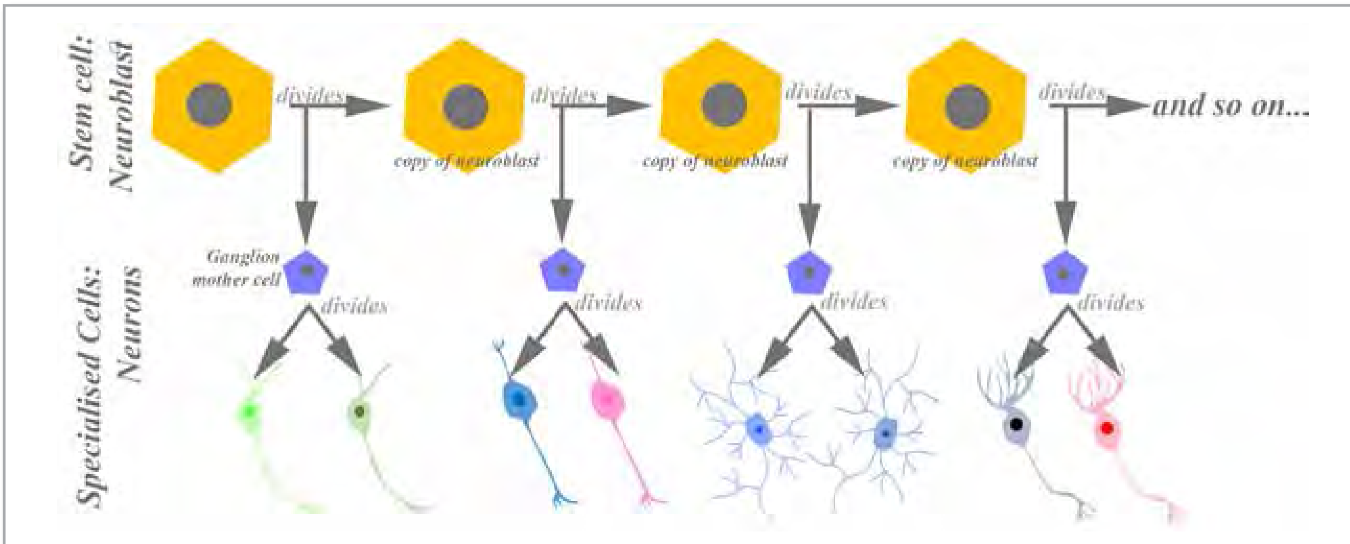


**Figure 2. Stem cells in development.** Stem cells are used in the development of many tissues to generate large numbers and types of cells. A stem cell divides asymmetrically: one of the cells is usually a specialised cell type, while the other is a stem cell. In the fly's nervous system, the stem cell is the neuroblast; and the specialised cell it produces with each division (the ganglion mother cell), divides once more to give rise to two neurons. Notice in this example that a single neuroblast has given rise to eight neurons with just four divisions.

'neuroblasts'. The specialised cells (called 'ganglion mother cells'), divide once more to give rise to two neurons that never divide again. This means that each time a neuroblast divides, it generates two neurons (as seen in Fig. 2).

Neuroblasts are formed very early in the development of the embryo. The fruit fly takes about ten days to metamorphose from an egg, through larval and pupal stages, into the adult fly. On the first day, the egg is shaped like a hollow rugby ball surrounded by a single layer of similar cells. Interactions between neighbouring cells cause some of them to enlarge and pop into the inside of the embryo. These enlarged cells are the neuroblasts. About 500 of them are formed along the entire length of the embryo, and go on to produce all of the 100,000 diverse neurons of the fly's nervous system!

How do such few cells produce all these different types of neurons?

### Making diverse neuron types

Neuroblasts do two things to achieve this. First, each time a given neuroblast divides, it produces different neurons (instead of the same one over and over again). Second, each of the 500 neuroblasts generates a different set of neurons[8] (as seen in Fig. 3).

But what makes one neuroblast different from another? And what makes each of them act differently over time? Neuroblasts use a system that is akin to using phone numbers. Each person has a different phone number, dialling which connects you specifically to them – a person's phone number is thus their unique identity code. Similarly, each neuroblast can be identified by a unique code of genes that are switched on in it, and in no other neuroblast.

Changes over time are accomplished by a very interesting strategy. If each neuroblast makes different neurons as it ages, it must have a way of 'keeping time'. In fact, neuroblasts do exactly this by using a 'molecular clock'! A molecular clock is set up by genes being turned on and off, in a tightly regulated sequence, over time. For example, gene 1 turns gene 2 on and is itself switched off; gene 2 then turns gene 3 on and is itself switched off… and so on. This will result in a sequence of genes that are turned on – first gene 1, then gene 2, then gene 3… and so on. So, if a neuroblast was in the 'time window' of gene 1, it would generate a certain kind of neuron; whereas if it was in the 'time window' of gene 4, it would generate a different kind of neuron, and so on.

In this way, a handful of initially similar neuroblasts acquire unique molecular identity codes (**combination** of genes that are switched on in it) that make them different from each other. In addition, a molecular clock (**sequence** of genes that are turned on) makes them change over time[8]. As a result of these

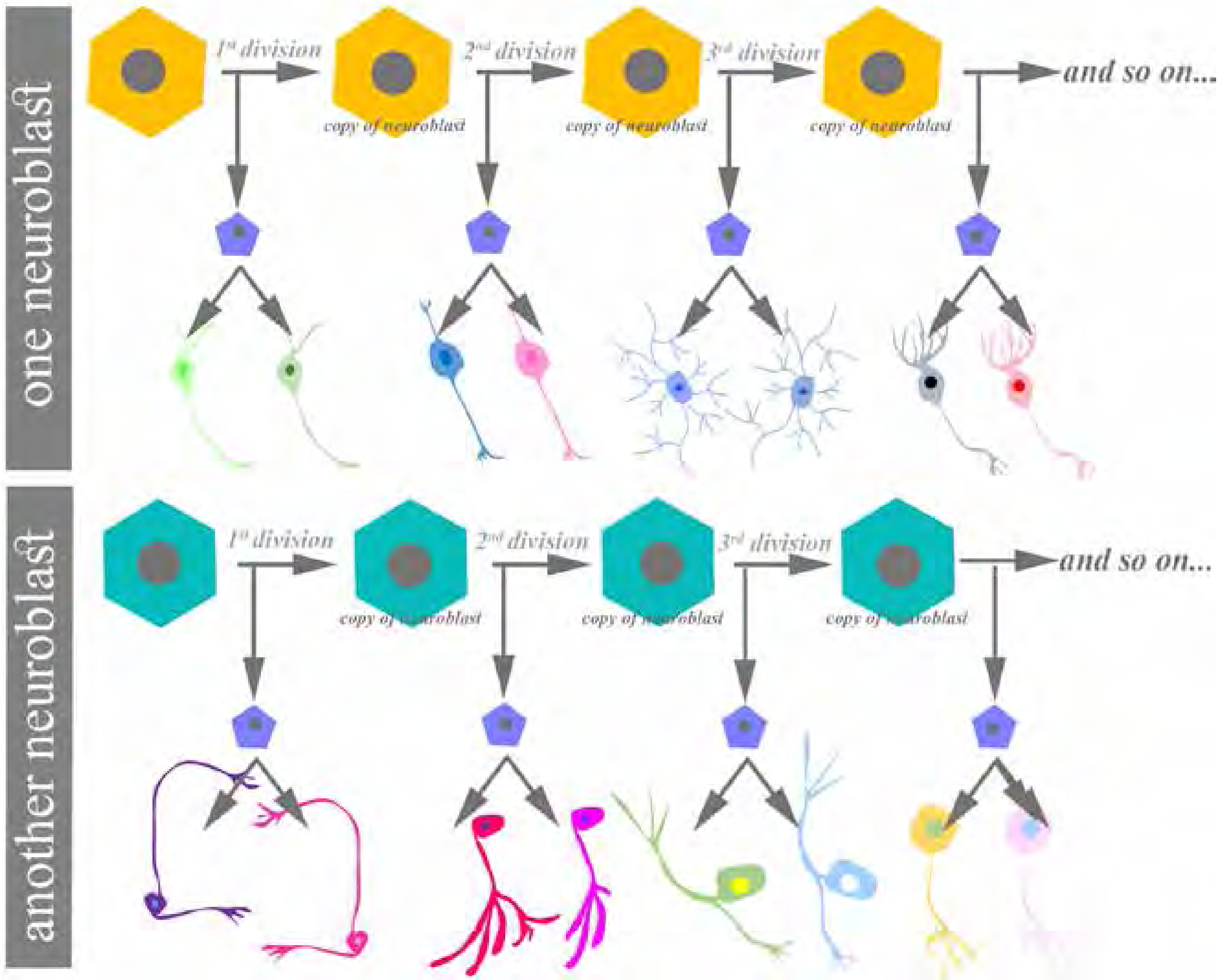


**Figure 3. Many different kinds of neurons are produced from a small pool of stem cells.** Each of the stem cells in the brain has a unique combination of genes switched on, and this makes each of them unique – like an identity code. This is represented as different coloured neuroblasts in the diagram above. Because each neuroblast is different, they can each generate a unique set of neurons. Over and above this identity code, another set of genes is switched on in a very precise sequence in the life of a neuroblast. This sequence allows a neuroblast to 'keep time', which it uses to generate different neurons at different times. In this image, you can see that with each division, different kinds of neurons are made. The interaction of these 'identity genes' with 'time genes', allows a few hundred neuroblasts to generate many thousands of different kinds of neurons!

interactions between genes over space and time, a few neuroblasts generate an amazing diversity of neurons in the brain!

**Modules in the brain**

Undoubtedly the most beautiful of principles that emerged from these studies has been that the brain does not have to be built piecemeal, but in modules. This is because neurons produced by a particular neuroblast tend to stay together and wire into the same functional sub-circuits in the brain. For example, a particular neuroblast called 'ALad1' in the fly brain makes about 120 neurons, all of which participate in the sub-circuit that allows a fly to smell. Similarly, another neuroblast called 'LALv1' produces another set of about 150 neurons that participate in the sub-circuit that allows the fly to process visual information while it flies[9]. This means that the fly brain does not have to have a strategy to control the wiring of 100,000 neurons, but only of about 500 modules of neurons. This reduces the wiring problem by many orders of magnitude (see Fig. 4)!

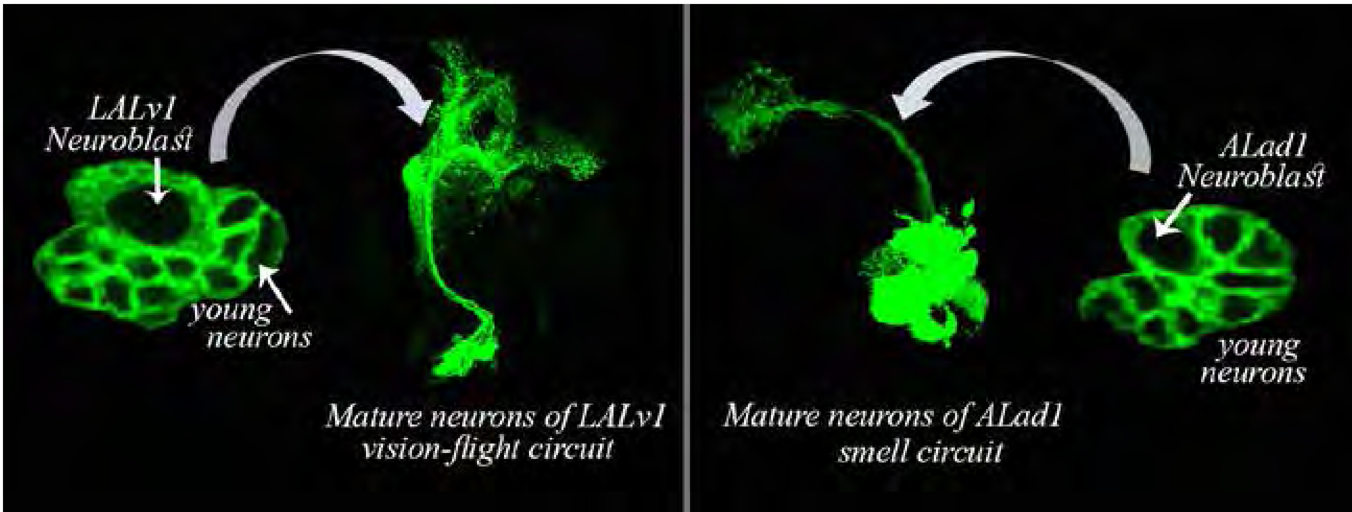


**Figure 4. The brain is built in modules.** Each neuroblast (the large cells) makes a series of neurons (the smaller cells) that initially stay together. Then, all of them wire into the same functional circuits. For example, all the neurons made by the LALv1 neuroblast wire into the circuit for processing visual information while the fly flies; all the neurons made by the ALad1 neuroblast wire into the circuit for smelling.

## Similarities across animals

Is any of this of broader significance or are they peculiar to flies? The kinds of experiments that allowed the numerous scientists across the world to work this out are much harder to do in animals other than in flies. But as information trickles in from ants, bees, fish, mice, and even humans, it's becoming increasingly clear that the general principles are the same, i.e., in the construction of the nervous system, neural stem cells use molecular codes and molecular clocks to generate diverse neuron types; and it is likely that they do this in modules. In fact, in many cases, even the genes used to achieve this are the same! Even more amazingly, the wiring diagrams of many of the sub-circuits they produce are also strikingly similar (refer Fig. 5)! So it is indeed true that insights gained through experiments in unlikely species like the fruit fly are very informative and useful for understanding nervous systems in general.

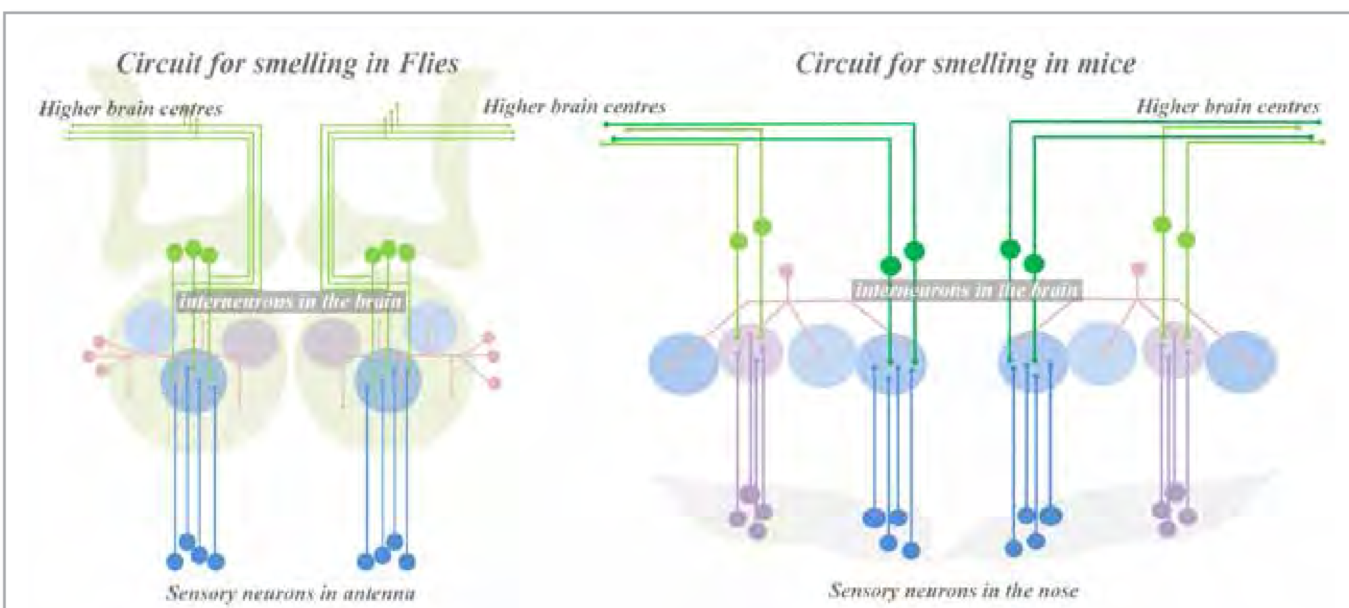


**Figure 5. Circuits in different animals have similar wiring diagrams.** Many functional circuits have the same kind of connectivity in different animals. For example, compare how sensory neurons in both the fly and the mouse connect to interneurons, transmitting information to higher brain centres. You'll notice that the connectivity is very similar in both cases (adapted from[10])!

## Conclusion

Over the years, people have been intrigued by animal behaviour and have applied different techniques to study various creatures and their behaviours. Each one of these techniques, and animals, has helped us understand how animals interact with their environment. The large neurons of squids are perfect to stick electrical probes into; the phenomenal genetic tools available in fruit flies allows us to understand how genes control the process; and mice are excellent models because of their 'closeness' to humans, which is especially important in understanding diseases. Yet, all that we've learned is only a humbling little in comparison to all that we do not know and understand. But along the way we have developed revolutionary new technologies that allow us to push the boundaries of what we know, and make many more exciting new discoveries about the brain and the nervous system!

## Resources

1. General overview of the nervous system and neuronal signalling: http://www.nobelprize.org/educational/medicine/nerve_signaling/game/nerve_signaling.html#/plot1

2. How to manipulate neurons with light: https://www.youtube.com/watch?v=I64X7vHSHOE

3. Watch hundreds of neurons fire spontaneously in the brain of a zebrafish[11]: https://www.youtube.com/watch?v=T2H6UdQVEFY

4. Watch thousands of neurons, in the young zebrafish brain, fire in response to different visual stimuli[12]: http://www.wired.com/2014/07/neuron-zebrafish-movie/

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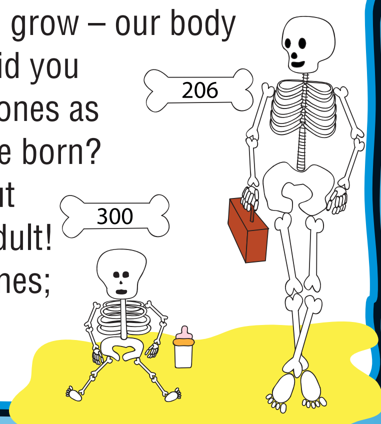
# TEN THINGS YOU DIDN'T KNOW ABOUT HUMAN BONES

SRIKANTH K.S

**1**

From the time we are born till when we reach adulthood (and even after that), we continue to grow – our body becomes bigger and stronger. But did you know that you actually have fewer bones as an adult compared to when you were born? Yes, at birth you have 300 bones, but end up with only 206 bones as an adult! Fear not, you have not lost these bones; they have simply fused (joined-up) with each other.




**2**

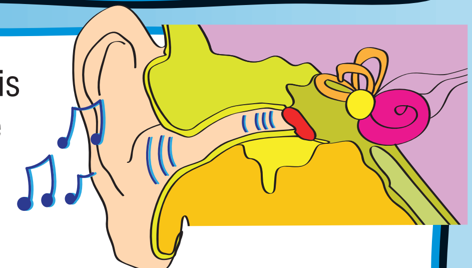
You may know your thigh bone (you can call it the femur to sound intelligent!) to be the longest and heaviest bone in your body. But did you know that it is also the strongest?
It is, in fact, stronger than concrete! A small matchbox sized piece of this bone can support nearly 9 tons of weight – four times the amount concrete can support! That is insanely strong – especially if you consider the fact that this bone is hollow!

**3**


Did you know that the largest joint in your body is the one in your knee? This joint is protected by a piece of flattish bone called the patella (kneecap). Babies are born with only a tough, flexible tissue (known as cartilage) covering this joint. But between the ages of 2-5 years, this cartilage starts hardening up to develop into the kneecap.

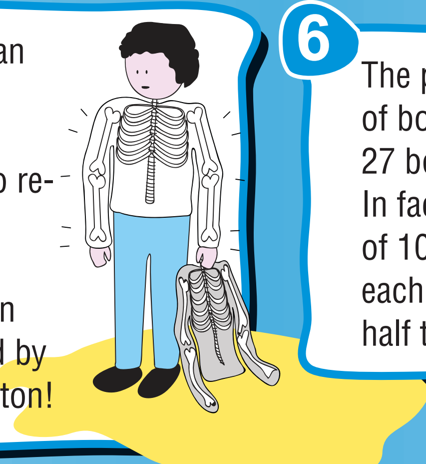
**4**

The smallest bone in your body is called the stapes (also called the stirrup bone). It is found in your inner ear and measures only 2-3mm in size! Did you know that this tiniest of bones has a big and important job in your body? Shaped like a 'U', this bone receives all sound vibrations that reach your inner ear and passes them along to your inner ear (cochlea), where it is finally interpreted by your brain.



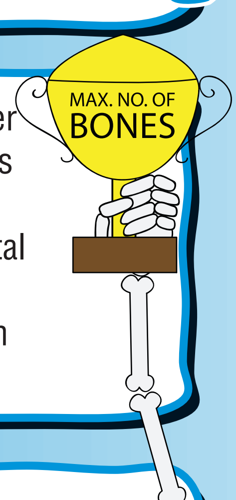
**5**

We all know that some organs in our body can continuously rejuvenate (re-grow). But did you know that your bones can also do that?
Yes, bones not only repair themselves, but also re-grow. Their constant day-to-day activity wears down your bones, but they are remade just as quickly. In fact, this happens so regularly that in seven years an old bone is completely replaced by a new bone, and we get a practically new skeleton!



**6**

The parts of your body with the maximum number of bones are your hands – each of your hands has 27 bones, 29 joints and 123 ligaments!
In fact, of the 206 bones in the human body, a total of 106 are found in just our hands and feet (27 in each hand and 26 in each foot). That is more than half the bones of the body!

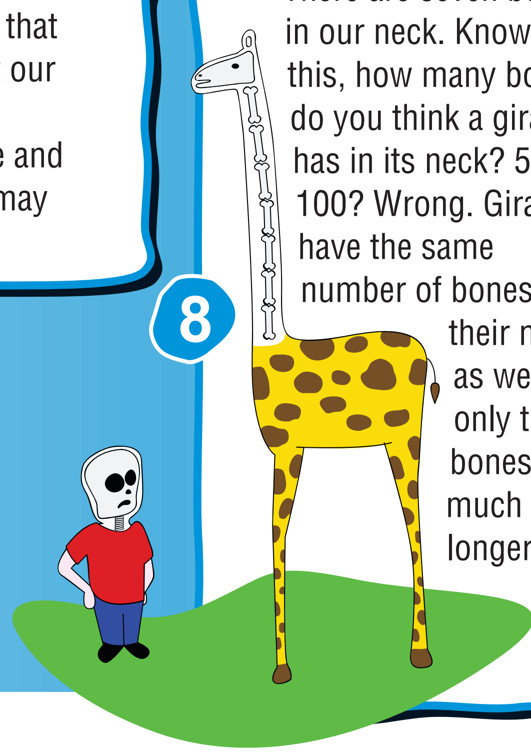



**7**

The human face is made up of 14 bones that protect our sense organs of sight, taste and smell. Did you know that these facial bones are constantly moving, throughout our lives, even if we don't really notice their movement?
As we become older, these movements become more and more apparent – this is why your grandfather's face may appear 'sunken'.

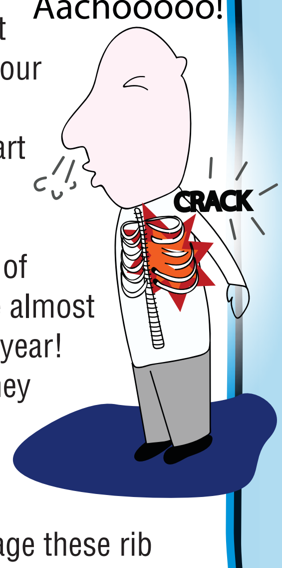
**8**

There are seven bones in our neck. Knowing this, how many bones do you think a giraffe has in its neck? 50? 100? Wrong. Giraffes have the same number of bones in their neck as we do; only their bones are much longer!



**9**

The horizontal bones of our chest are called ribs. These bones form a cage that protects two of our most important organs - the heart and lungs. As a result of our breathing, each of these ribs move almost 50 lakh times a year! But strong as they are, sometimes even a strong sneeze is enough to damage these rib bones. That is scary!




**10**

Gorham's (pronounced GOR-amz) disease (also known as vanishing bone disease) is one of the most mysterious diseases known. In this disease, instead of getting repaired, a fractured bone breaks down gradually until it completely disappears.
What is strange is that although this disease has no known treatment, in some cases, the disease gets cured, mysteriously, all by itself. No one knows how or why, but in these cases, its symptoms completely disappear!



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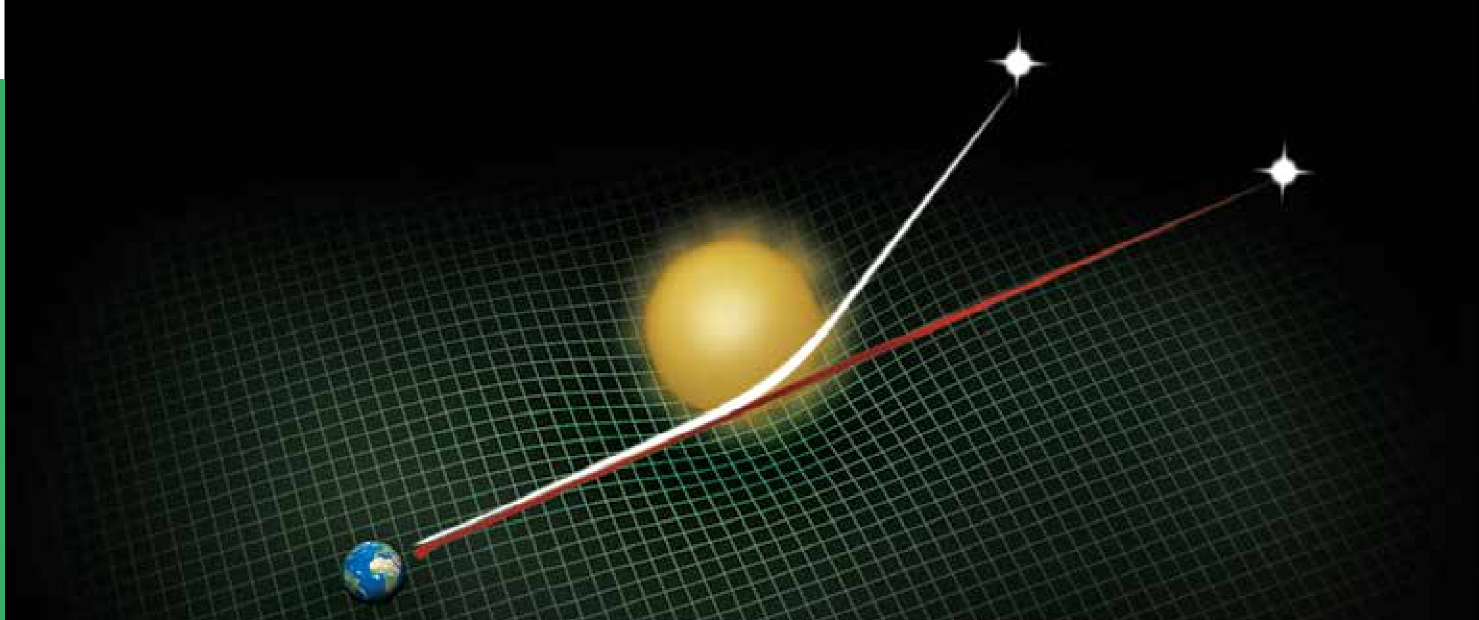
Azim Premji University



# WHY DO EXPERIMENTS?

BHAS BAPAT

We are bequeathed a legacy of clever and painstaking experiments by the pioneers of modern science. In the age of information overload, it is prudent to consider why we need to dirty our hands doing experiments, instead of merely depending on processed information to push the frontiers of science.

Science is driven by human curiosity; curiosity to know why things happen the way they happen, or in other words, to understand how nature works. This curiosity gets channelised in many ways, two of which we can readily identify with.  The first is to make careful observations of phenomena, identify factors affecting a particular effect or outcome, and then attempt to control the outcome by tweaking the influencing factors, thus establishing a cause–effect relationship.   The other is to predict a cause–effect relationship by applying logic about how things should be without necessarily working out the ideas in practice. In the formal world of science, these two approaches are readily identified as experimental research and theoretical research respectively. However, contrary to common belief, these are not distinct streams, nor is one cleverer or purer than the other. Instead, they complement and supplement each other. An experiment (or a series of experiments), is no good if the inferences drawn do not help us build a more general or wider understanding of phenomena. Likewise, a theory is no good if it does not explain a set of observations or make correct predictions about things not yet observed. Very often, though not always, a theory is based on axioms or postulates that are a distillation of inferences based on observations. Humans are naturally trained to believe only what they are able to perceive with their five senses. A non-scientist is therefore likely to ask 'But, is it real?' for something that a trained scientist will accept as second nature, even if it can't be seen or perceived with the senses. A case in point is the microscopic world.  We believe in atoms and sub-atomic particles, though nobody has really 'seen' them.  This is so because we have been able to build an edifice of knowledge by making certain postulates,

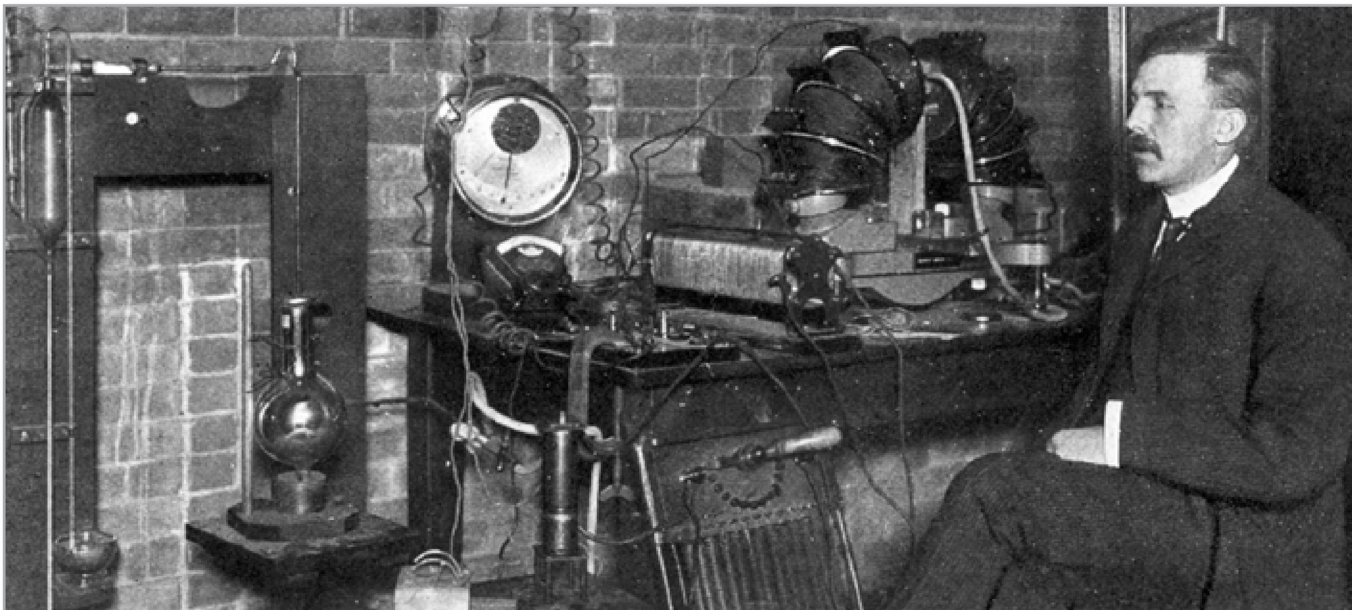


**Figure 1. Ernest Rutherford with his apparatus for studying radioactivity**. An apparatus is merely a tool that puts out some numbers. It is the inferences drawn from the numbers that may have far-reaching implications in science, as they did in this case. They also brought Rutherford fame by way of a Nobel Prize. Source: Contributor unknown, published in 1939 in Rutherford: being the life and letters of the Rt. Hon. Lord Rutherford, O. M - http://wellcomeimages.org/indexplus/image/L0014629.html. Wikimedia Commons. License: CC-BY. URL: https://en.wikipedia.org/wiki/Ernest_Rutherford#/media/File:Ernest_Rutherford_1905.jpg.

which appear reasonable based on experimental observations, and then applying logic.

So, experiments serve three main purposes. First, obtaining information about phenomena that have not been understood before, which in turn assists the development of a theory pertaining to those phenomena and enhances our ability to make predictions. History of science throws up innumerable examples. The development of the concept of an atom and the particulate nature of matter and the associated concepts of heat and temperature are largely based on insightful analysis of chemical and physical reactions. The second purpose of experiments is to verify or reject the predictions of a theory. Some outstanding examples of this include the demonstration of the quantisation of angular momentum of atoms by Stern and Gerlach, and the measurement of the bending of light due to the sun's gravitational field by Eddington and his collaborators. In more recent times, the discovery of various particles in high energy particle collisions has confirmed the predictions of the Standard Model. A famous experiment that rejected a popular theory is the Michelson Morley experiment; it sounded the death knell for the all-pervading ether. The third purpose that experiments serve is paving the way for application of science for societal benefits. There are simply too many of them to list, but one outstanding example is the Haber process that enabled fixation of atmospheric nitrogen as ammonia which plants could use as a nutrient - a process that was the key to scaling up of agricultural production to meet the burgeoning population and associated food shortages. One field that has benefited enormously from relentless experimentation, in diverse streams of chemistry and physics, is medicine. Diagnostic tools such as biochemical analysis, ultrasonography, X-ray, NMR, minimal invasive interventions and therapies are a fall-out of a series of experiments, in domains where theory is far too complex and intractable, if not unknown. Many scientific discoveries have been serendipitous, and it is easy to see that the more you tinker, the more likely you are to hit something big.

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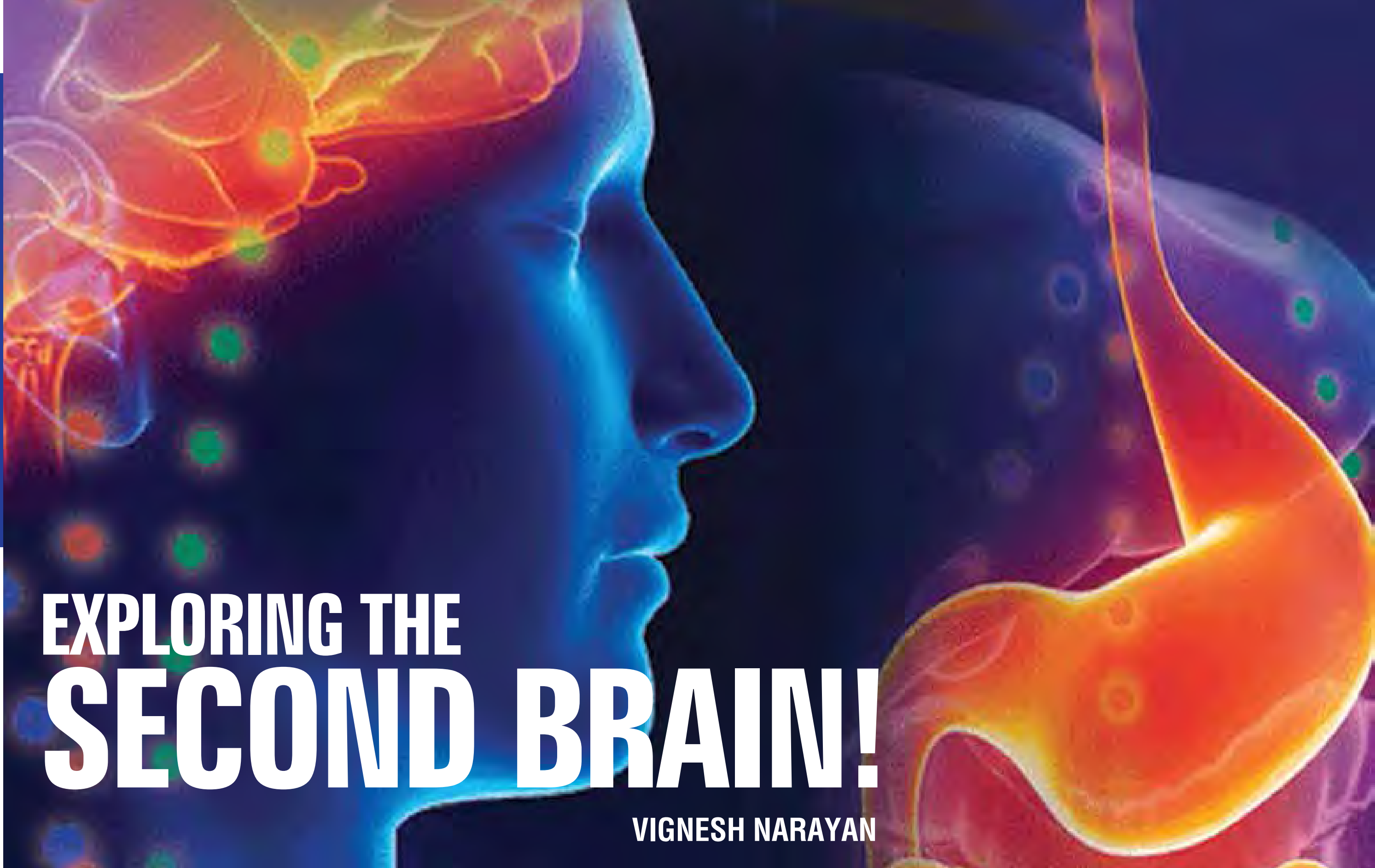


# EXPLORING THE SECOND BRAIN!

VIGNESH NARAYAN

Join the author in an exciting narrative about the Gut, a small but amazing organ that does so many things that it is called the second brain. From digesting anything that is put in it to controlling feelings and emotions, the Gut is a Jack of all trades, and a master in every one of them.

*"Located neither high nor low, soft at heart and smooth in flow, my job is serious, I'll let you know! I crush and grind and pump all day, filled with lakes that can eat iron nails. I can sense everything that comes my way, sometimes I quiver with joy, sometimes I groan in pain!"*

You are here at last! I have been waiting for you today, to show you some of the wonders of your body, and my humble job here as a small but important organ. Before we begin, let us play a guessing game. If you can guess who I am, I'll never give you any trouble again, and as far as I am concerned, everything in your body will flow smoothly. Oops! Almost gave myself away. Well, without further ado, here is a tricky question for you – what has close to five hundred million (that is 5 followed by 8 zeros!) neurons (nerve cells), receives and sends electrical signals to muscles as well as other nerves, and produces more than 90% of the serotonin (a chemical that acts as a 'neurotransmitter'- which means that it helps transmit information across the body through neurons) and 50% of the dopamine (another neurotransmitter) found in the body?

I, my friend, am called the Gut. Located just below the stomach, I am the last part of the largest structure in the digestive system, called the 'gastro-intestinal tract'. This is not a very difficult word to understand. 'Gastro' refers to the stomach (from the Greek word gaster which means belly); 'intestinal' refers to the small and large intestines in the abdomen; and 'tract' just means a really large area, or, in this case, a really long tunnel. The digestive system is like an assembly line in a factory. The food you eat moves down this assembly line, along which there are different kinds of specialized cells and organs that pour different kinds of enzymes (proteins that perform certain biological reactions) that digest the food. Each section of your digestive system has a gate called a 'sphincter' (sfink-ter) to allow food to enter a certain section of this factory and keep it there until it is digested partially or

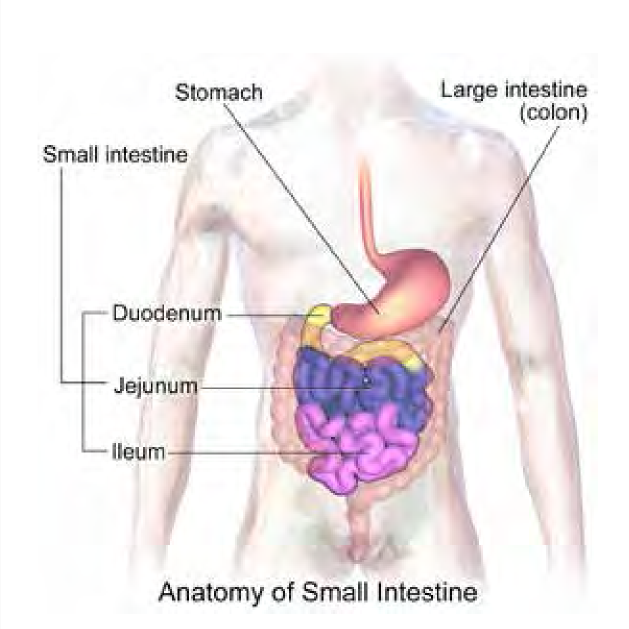



**Figure 1.** Anatomy of the small intestine. Source: Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762. URL: https://en.wikipedia.org/wiki/File:Blausen_0817_SmallIntestine_Anatomy.png. License: CC-BY.

completely. Whenever it is my turn to digest food, the pyloric sphincter opens up - in gushes a mass of semi-digested food, ready for me to process.

I am made up of two parts - the first of which is called the 'small' intestine because it is narrow and highly convoluted. The second part - called the large intestine, receives material from the small intestine, and helps remove the undigested waste from the body through an opening called the anus. Interestingly, while the large intestine is only about 4.5 feet long, the small intestine measures 19 feet in length! Although the small intestine is about three and a half times the average length of an entire human body, it is folded and packed so neatly that it looks smaller than even the large intestine. Let me tell you the reason behind this packing. The inner walls of the small intestines are not flat, but folded up into pleats, like the ends of a dhoti. Each of these pleats is covered with tiny projections called 'villi'. Each villi, in turn, is covered with cells, which have tiny hair-like structures covering its surface. In this way, about 5.8 metres of the small intestine has an absorptive surface of almost 250 square metres. That is 7 times the surface area of the small intestine if it were not folded up and slightly larger than a tennis court!

You may make the mistake of thinking that I am just a long pipe - after all, who wouldn't! However, there is more to me than meets the eye, my friend. My walls are made up of strong involuntary muscles (smooth thin muscles that cannot be controlled voluntarily, like the ones controlling your bladder which force you to run to the bathroom in the middle of class!), whose powerful motions push semi-digested and digested food through the entire canal. Like the rest of the digestive tract, lining my walls are millions of specialized cells that pour out digestive enzymes onto the food. Needless to say, by the time the food you eat reaches your anus, there is not a tiny speck of nutrition left, for I have absorbed all of it!

Let me give you an exact break-down of what happens as soon as food enters my walls. Once the stomach finishes with its job of breaking proteins into smaller units, I step in as the major organ of digestion, and the only part of your entire body that can absorb nutrients from the food and eject the waste material left behind. To digest the food from the stomach, I work along with your pancreas. The pancreas, as you know, is an organ that produces a huge variety of enzymes that are absolutely essential for your body. These pancreatic enzymes, enter my walls through small ducts or tubes, and break down peptides (short pieces

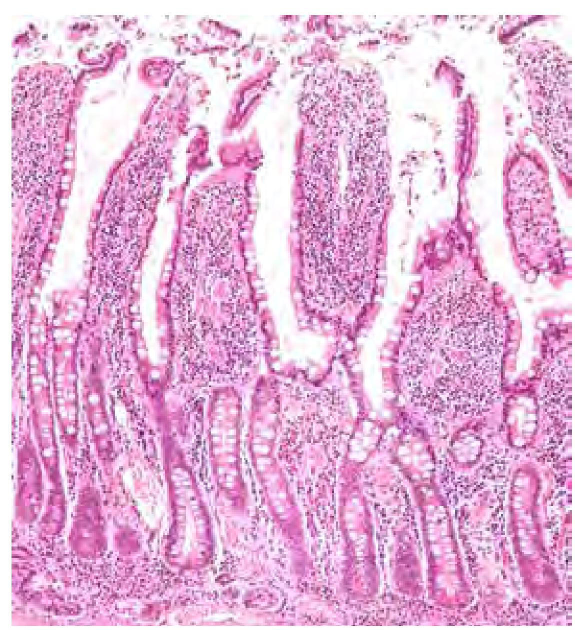


**Figure 2.** A micrograph of small intestinal mucosa showing intestinal villi. Source: Nephron, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Small_intestine_low_mag.jpg. License: CC-BY-SA.

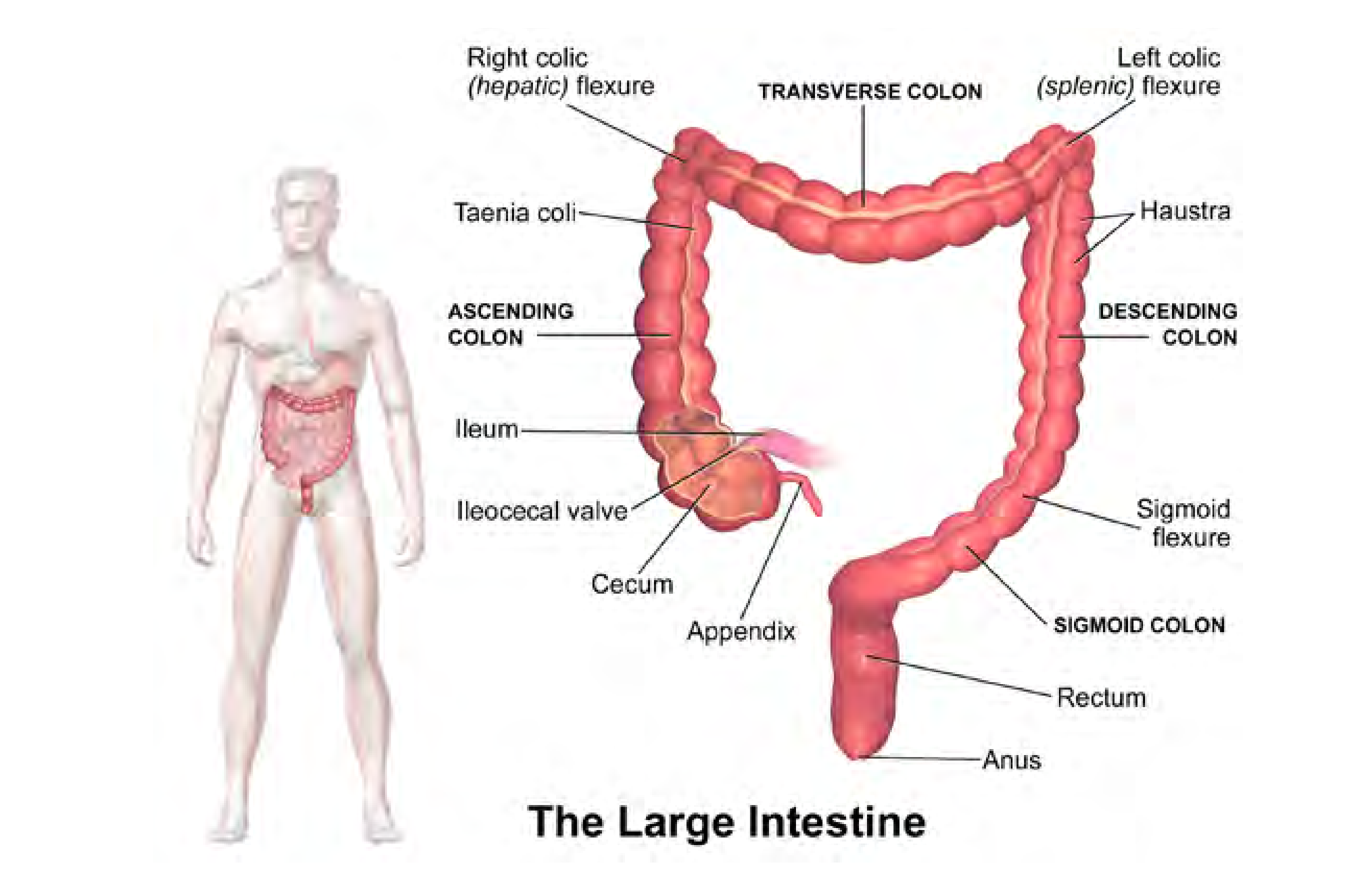



**Figure 3.** The large intestine. Source: Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762. URL: https://en.wikipedia.org/wiki/File:Blausen_0604_LargeIntestine2.png. License: CC-BY.

of degraded proteins) and amino acids (smallest units that make up proteins), lipids (fatty foods), and some carbohydrates (commonly called sugars). Let us not forget one of the most important chemicals that enter my walls - bile. Produced by the bile duct, bile helps neutralize the horribly strong acid that the stomach uses to break proteins into smaller peptides. The pH of the stomach can go down to three, which is strong enough to digest razor blades!

Once the food passes through my first compartment, it enters the large intestine (which is actually much smaller) where I store the waste (left after the small intestine has finished with it!); and absorb water, ions (like potassium), as well as vitamins produced by bacteria that make their home here (I'll talk more about this later). By the time the food has reached the large intestine, I absorb most nutrients and 90% of the water, leaving behind a few electrolytes like sodium, magnesium, chloride and indigestible foods (mostly plant carbohydrates). As the food moves down towards the anus, most of the remaining water is

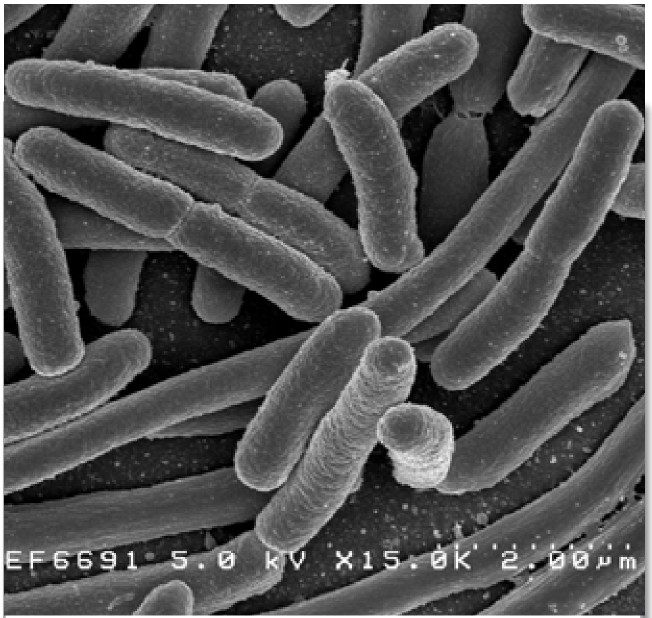



**Figure 4.** *Escherichia coli* is one of the many species of bacteria present in the human gut. Source: Rocky Mountain Laboratories, National Institutes of Health, United States Department of Health and Human Services. Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:EscherichiaColi_NIAID.jpg. License: Public Domain.

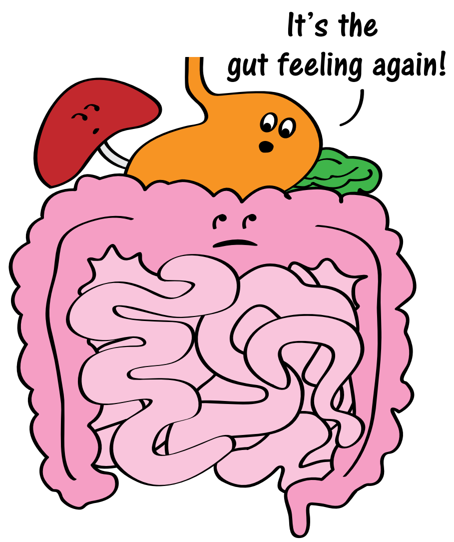


**Figure 5.** Have you ever had a 'gut feeling' about someone you have met?

removed, and the waste matter is mixed with mucous and bacteria (known as gut flora) and becomes faeces (also called stools). This way, the stools gradually become more solid as my strong muscles slowly push them along to their ultimate fate - the toilet!

Enough about these trifling things that everyone learns in school! Today, I'm going to let you in on secrets that scientists are only now figuring out. Did you know that for every human cell in your body, there are ten bacterial cells! That's right! Some people estimate that there are over $4\times10^{13}$ bacterial cells (that is 4 followed by 13 zeroes!) in your body. Some of these bacteria live on your skin (especially where there is a lot of hair) and your urogenital tract, but over 90% of them, my friend, grow inside me. The entire population of bacteria living inside the human body is called the 'human microbiome', and the most important and dense microbiome in the human body is the 'gut microbiome'. Many people even go so far as to say that the gut microbiome is a forgotten organ, and I am inclined to think that they are absolutely right. The number of different species of bacteria inside me is more than twice the number of genes in a single human cell! That means that there are over 50,000 different species of bacteria, and all of them live on my inner surfaces.

What are they doing there, you ask? Well, I keep them because they make for wonderful factories! Bacteria are the most marvellous machines that nature has created; they can live on almost anything, and produce

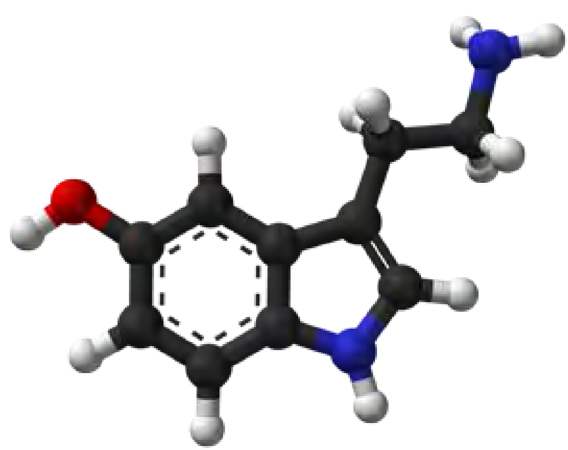


**Figure 6.** Ball-and-stick model of the serotonin molecule, C10H12N2O. Source: Ben Mills, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Serotonin-Spartan-HF-based-on-xtal-3D-balls-web.png. License: Public Domain.

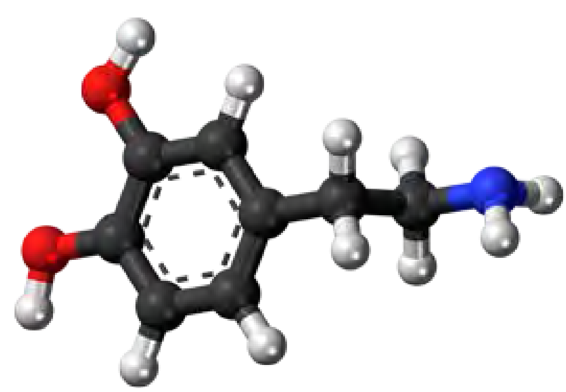
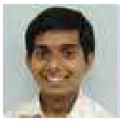


**Figure 7.** Ball-and-stick model of a molecule of dopamine - a neurotransmitter that affects the brain's reward and pleasure centers. Source: Jynto (talk), Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Dopamine_3D_ball.png. License: Public Domain.

and secrete some very interesting compounds. My microbiome produces enzymes that digest food which I would find very difficult to break down myself. In addition, they produce important vitamins like vitamin B and vitamin K, without which your body will be subject to many horrible diseases. Recent research has positively proved that tampering with my microbiota in **any** way – be it removing the diversity (number of different types), or the numbers (population size), can cause obesity, anxiety disorders, depression and even autism! But I must add a note of caution. Sometimes, the bacteria that colonize me can be harmful - specific species of bacteria can cause cancer if they start dividing inside me.

If you still haven't realized that there is more to me than meets the eye, prepare to be completely astonished! I, your gut, a narrow tube running from your stomach to your buttocks, am your second brain. Have you ever had a 'gut feeling' about someone you have met? A 'gut instinct' that your guess in a difficult quiz question is correct? A sinking feeling in your stomach when you feel that something bad is going to happen? If you think that your brain makes most of your split-second decisions, think again. I am connected to your brain via the 'enteric' (meaning inside) nervous system, and am a whole brain hidden inside your body cavity! There are hundreds of millions of neurons connecting my walls to your brain. My neural networks are so sophisticated that I can work and think without any control from your brain. This enteric nervous system of mine not only ensures that the food is digested and ejected at a certain time and speed, but also dictates how you feel. I make and secrete a very important molecule called serotonin. Serotonin is a neurotransmitter (a chemical used by the brain, remember?) that controls your mood, appetite, sleep, memory and learning; and, regulates your temperature, social behaviour and libido. Serotonin is also important in the functioning of other organ systems like the cardiovascular system, the muscular system and some parts of the endocrine system. I could go on and on about the importance of serotonin! The more scientists discover the uses of serotonin, the more they realize that I run the body, not the brain. Simply because I produce 90% of all the serotonin your body needs; not to mention 50% of your dopamine, without which parts of your brain cannot talk to other parts!

The next time you feel sleepy, or cannot think clearly after eating, don't blame your brain. This is just me and the trillions of bacteria that I grow trying to take charge! Butterflies in your stomach? Feeling excessively happy? Me again! Now that you know this, I'm sure you will be more careful with what you put in your stomach. Remember to eat good quality food, at the right time and in the right quantities. All this talk has made me hungry - I think you should go get some pizza!



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# THE DEMOTION OF PLUTO

RAMGOPAL (RAMG) VALLATH

How did we discover the existence of Pluto? Why have we reclassified Pluto as a dwarf planet? What do we know of other dwarf planets? How do we decide if a celestial body is to be classified as a planet or not? Read on for a first-hand account by Pluto.

Life is not fair, I tell you. I used to live my life peacefully, far, far away from all of you. My life was uncomplicated here, in the far reaches of the solar system. Then one day, you ‘discovered’ me, and bestowed on me the honour of calling me a planet. But since then, you have systematically belittled me – today, I have even been booted out of the planetary club! This is so unfair.

You human beings searched for me for quite some time before finally discovering me. It all started in the early 19th century, when astronomers from your planet, identified some perturbations in the orbit of Uranus that could only be explained by the gravitational force exerted by an undiscovered planet beyond its orbit. Their search for this unknown planet led them to Neptune. But in the late 19th century, their calculations suggested that Neptune’s presence was not sufficient to explain the extent of these perturbations. Your astronomers predicted another planet, and that is how the search for a so-called ‘Planet X’ started. Finally, in 1930, Clyde Tombaugh ‘discovered’ me.

You named me Pluto, after the Greek god of the underworld. I was happy to see that you gave me immediate entry into the elite club of the solar system, consisting of the planets. It is not my fault that you had

**Charon**, Pluto’s moon is half as massive as Pluto. This high mass ratio is quite unique for a planet - satellite system in the Solar system. Because of this, the centre of mass of the two bodies lies outside Pluto, in between Pluto and Charon. So in effect, Charon is not orbiting around Pluto; instead, Pluto and Charon, together, are circling their common centre of mass every 6.5 Earth days.

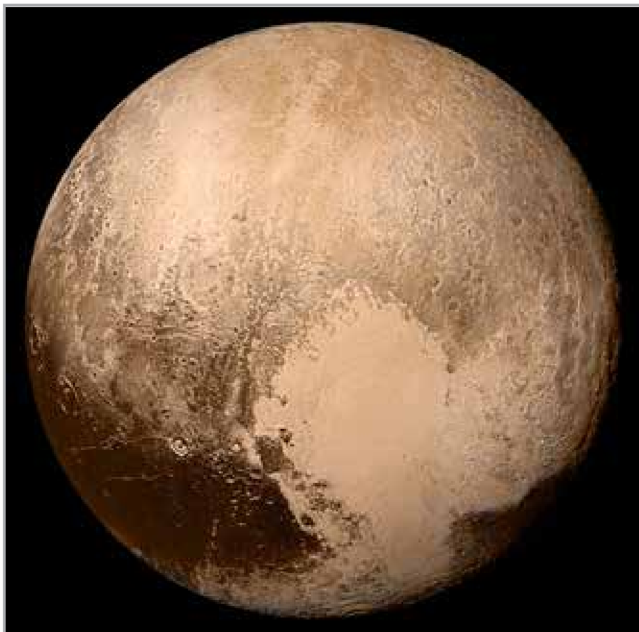

**Figure 1.** Pluto - New Horizons - July 14, 2015. Four images from *New Horizons*, an interplanetary space probe launched to perform a flyby study of Pluto. The images were taken when the spacecraft was 450,000 kilometers away and show features as small as 2.2 kilometers. Credits: Applied Physics Laboratory/Southwest Research Institute, NASA/John Hopkins University. URL: https://en.wikipedia.org/wiki/Pluto#/media/File:Nh-pluto-in-true-color_2x_JPEG-edit-frame.jpg. License: In Public Domain.

**Figure 2.** Pluto, the Plutoids, and the Kuiper Belt. Source: NASA (NASA.gov). URL: https://i.ytimg.com/vi/2kNZ6bbHunU/maxresdefault.jpg. License: CC-BY-NC

over-estimated my mass! At first, you thought my mass was equal to that of your home planet, Earth. Then, in 1948, with better calculations, you brought down this estimate to about the same mass as Mars. Later, in 1978, you discovered Charon, my satellite. Studying Charon's orbit, you were able to infer my actual mass as being not 0.1 or 0.01, but 0.00218 times the mass of Earth!

That is not all. With an improvement in your methods to study space, you started discovering many of my companions - objects that are at about the same distance from the Sun as I am. I remember you discovering the first of these in 1992. These numerous objects (about 100,000 of them), known to you as the Kuiper Belt, circle the Sun at a distance of 30AU to 50AU from it.

AU (Astronomical Unit)– is a unit of distance and is defined as approximately the average distance of the Earth to the Sun. Today, AU has been given a precise value of 149,597,870,700 meters or approximately 150 Million km.

While I was happy to see that you'd discovered many of my companions, this was the beginning of a further downfall in my status. Your scientists started questioning whether I could really be thought of as a planet, when I seemed like one of so many other celestial bodies. My orbit at 0.249 eccentricity, as they pointed out, is more eccentric than that of all the other planets; and at 17.14°, so is my inclination. In both of these characteristics, I am more like one of the KBOs (Kuiper Belt Objects). Thus started a further series of

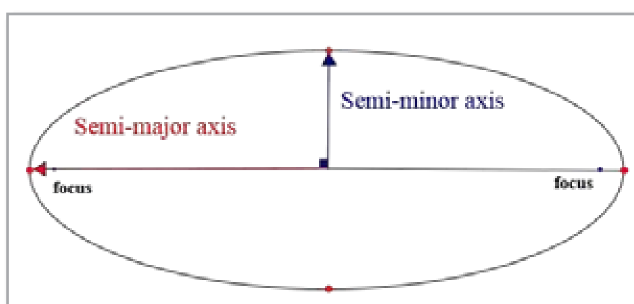


**Figure 3.** Major Axis and Minor Axis of an Orbit. Credits: Sae1962, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Semi-major_axis#/media/File:An_image_describing_the_semi-major_and_semi-minor_axis_of_ellipse.svg. License: CC-BY-SA.

**Semi Major Axis, Aphelion, Perihelion, Eccentricity and Inclination**

Planets (and dwarf planets/comets) orbit the Sun in an elliptical orbit. The major axis of the orbit is the longest diameter of the ellipse. Half of this is called the **semi-major axis**. The **aphelion** is the distance from the Sun to the farthest point on the orbit and the **perihelion** is the distance from the Sun to the closest point on the orbit. **Eccentricity** is a parameter that defines how 'squashed' an ellipse is. When the ellipse is not 'squashed' at all, it is a circle and the eccentricity is 0. The eccentricity of an ellipse varies from 0 to 1. The **inclination** of a planet (or dwarf plant/comet) is defined as the angle between its orbital plane and Earth's orbital plane.

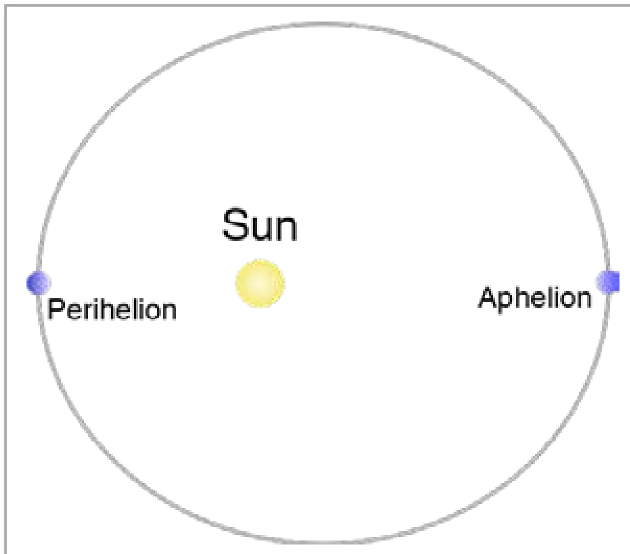


**Figure 4.** Perhelion and Aphelion of an Orbit. Credits: Chris55, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Perihelion_and_aphelion#/media/File:Perihelion-Aphelion.svg. License: CC-BY-SA.

**Table 1:** Distance from the Sun, Eccentricity and Inclination of some Celestial Bodies

| Celestial Body | Minimum distance from the Sun (Perihilion) (AU) | Maximum distance from the Sun (Aphilion) (AU) | Eccentricity | Inclination (degree) |
|---|---|---|---|---|
| Mercury | 0.307 | 0.466 | 0.205 | 7.005 |
| Venus | 0.718 | 0.728 | 0.007 | 3.394 |
| Earth | 0.983 | 1.016 | 0.017 | 0.000 |
| Mars | 1.381 | 1.666 | 0.093 | 1.851 |
| Jupiter | 4.950 | 5.454 | 0.048 | 1.305 |
| Saturn | 9.024 | 10.086 | 0.054 | 2.484 |
| Uranus | 18.33 | 20.11 | 0.047 | 0.770 |
| Neptune | 29.81 | 30.33 | 0.008 | 1.769 |
| Pluto | 29.66 | 49.32 | 0.249 | 17.14 |
| Eris | 37.91 | 97.65 | 0.440 | 44.04 |

Source: Wikipedia, individual pages of each planet/dwarf planet.

insults - your astronomers and planetariums started omitting me from the list of planets!
The final nail in the coffin was the discovery of my cousin, Eris. She is way more eccentric than I am. Her eccentricity is 0.44. (she really travels quite a bit every revolution, going as far away from the Sun as 97AU, but coming as close as 38AU – which is even closer than my orbit at times). But what is worse is that, even though she is slightly smaller than me in size, it turns out she has about 27% more mass than me.

**Additional Resources:**

The multimedia link on the New Horizons mission page (http://pluto.jhuapl.edu/) has many colourful resources on Pluto.

This link on the New Horizons mission page (http://pluto.jhuapl.edu/Participate/teach/Activities.php) has several lesson plans and classroom activities for school students - a useful resource for teachers.

The discovery of two other objects, similar to me in size - called Sedna and Quaoar - forced astronomers to either call all of them planets or demote me too. That was all that was needed. You started baying for my blood.

Finally, at the meeting of the International Astronomical Union, on 24th August 2006, the assembly voted to reclassify me as a Dwarf Planet. I can tell you this - I was devastated. The folks at IAU also came up with some criteria for defining various objects in the solar systems, which makes my re-entry as a planet seem pretty difficult.

1. A planet is a celestial body that: (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.

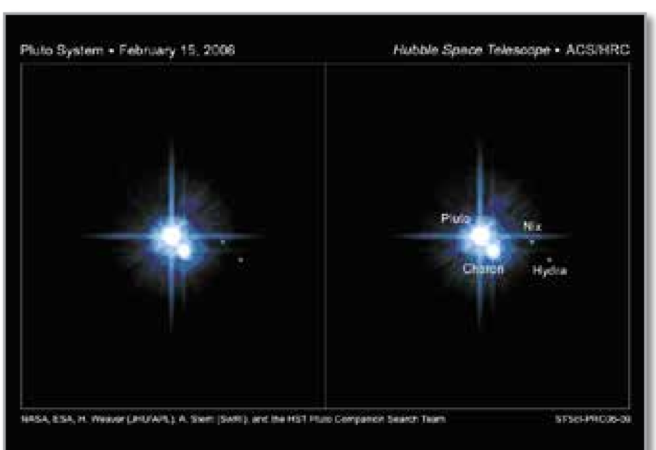


**Figure 5.** Other companions of Pluto - Nix and Hydra. We are able to see them at visible wavelengths because they are reflecting sunlight, despite their enormous distance from the Sun - suggesting that their surfaces could be icy and shiny. Source: Hubble Space Telescope.

2. A 'dwarf planet' is a celestial body that: (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

3. All other objects orbiting the Sun shall be referred to collectively as 'Small Solar System Bodies'.

As you can see, I am very clearly not category 3. Unfortunately, I was born into a very busy neighbourhood, with tens of thousands of other objects near me. So while I fulfil the criteria of orbiting the Sun, and have sufficient mass for my self-gravity to overcome rigid body forces and give me a nearly round shape, I have not been able to clear my neighbourhood. So, on 24th August 2006, I was summarily booted out of the planetary club.

What gives me hope is the huge outcry by other, the non-astronomer kind, people on your planet about my demotion (at least 7 popular songs lament my humiliation) that forced the high and mighty astronomers to quickly make some concessions. They created a separate category of celestial bodies, named Plutoids, in my honour.

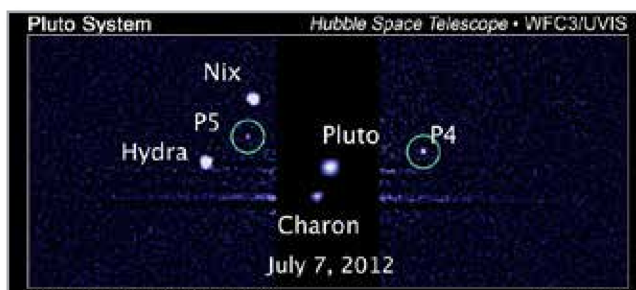


**Figure 6.** Two more companions of Pluto, P4 and P5 (subsequently named Kerberos and Syx), were discovered in 2010. We are able to see them also at visible wavelengths because they are reflecting sunlight, despite their enormous distance from the Sun - suggesting that their surfaces could be icy and shiny. Source: Hubble Space Telescope.

Plutoids are celestial bodies in orbit around the Sun at a semi-major axis greater than that of Neptune, with sufficient mass for their self-gravity to overcome rigid body forces and assume a hydrostatic equilibrium (near-spherical shape), but have not cleared the neighbourhood around their orbit.

Well, so what if I am not a Planet?! Look at the planet you call home - while it is part of the planetary club, with heavyweights like Jupiter and Saturn around, it seems like just an insignificant dot in that group. In contrast, I am king among the Kuiper Body Objects (KBO) and even have a group named after me. I want you to remember one thing - about four billion years from now, the Sun will run out of all its fuel, with all its hydrogen fused into helium. Once this happens, the outer shell of the Sun will expand outwards as it becomes a red giant. Mercury, Venus and most probably your Earth will all be swallowed up by that monster. I, on the other hand, will be safe, far away from all the destruction, and still undisputed King of the KBOs!

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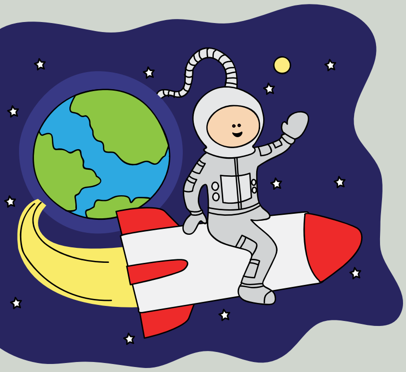
**Ramgopal (RamG) Vallath** is a bestselling author and motivational speaker. He is the author of the humorous, wacky science fiction book, 'Oops the Mighty Gurgle'. Apart from delivering motivational talks to students of high schools and colleges and employees of corporates, RamG's favourite pastime is delivering science workshops to middle school students. His public profile is www.ramgvallath.com, twitter id is @ramgvallath and email ID is ramgopal.vallath@gmail.com.

## Solid Gases and Metal Vapours

*– Vignesh Narayan*

Among the many wonders of space are planets. They come in all sizes, colours and most strikingly, chemicals. Extremes of temperature, gravitational forces and velocities cause chemicals to behave in ways that are rarely seen on Earth.

NASA's New Horizons spacecraft displayed the first ever images of Pluto, the dwarf planet, in 2015, after a 9-year voyage in space. These pictures show smooth plains of nitrogen ice arising from Pluto's 'heart' meeting mountains several kilometres high. These mountains are actually gargantuan icebergs that are resting, and move around on layers of solid nitrogen below them.

Closer to the sun, Mercury actually has thin vapours of sodium and potassium gas above its surface. Jupiter, known as a gas giant, has no surface at all! The top quarter of the planet is faced with such high temperatures and pressure that hydrogen atoms are stripped of their electrons to form a liquid metal. What makes the atmosphere of Jupiter even more interesting is a layer of ammonia and hydrogen sulphide crystals sandwiched between water ice at the bottom and ammonia ice on top. The planets Uranus and Neptune have clouds made of crystalline methane. Since methane absorbs all wavelengths other than blue, both planets appear blue in colour when seen by space probes and telescopes.

None of the planets or moons in the Solar System has an atmosphere similar to that of Earth. This means that if humans travel to other planets, they will have to take their own atmosphere along in order to survive!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# Interview

## WITH LOLITIKA MANDAL

Lolitika Mandal is an Assistant Professor at the Indian Institute of Science Education and Research (IISER), Mohali. Her research has contributed to a global understanding of how blood cells develop. In this interview, she shares her experiences and insights on the life of a scientist.

### Tell us something about your current work.

We are interested in understanding how blood cells develop (haematopoiesis). To do this, we use the fruit fly (*Drosophila*) as a test model. The fruit fly is a small insect (a fully grown adult is only a few millimeters in size!) that gathers around very ripe/rotting fruit.

You may wonder why we use an insect for our studies – after all, insects do not have blood like we do. How can anything we learn about the process of blood formation in insects be relevant in humans?! As it happens, fruit flies (and all other insects) have a fluid - called haemolymph, which is very similar to blood. It circulates within the insect body, remains in contact with all its body tissues and is composed of cells that are very similar to the cells in our blood. What's more, the cells in both these fluids develop in very similar ways!

But, you may ask, why not just study the development of human blood in humans? The cells in human blood are short-lived. They are produced and their numbers continually replenished by the division of some special cells called the haematopoietic stem cells. The specific physical location of these cells, within the body, is called their 'niche' (pronounced *nee-sh*). Turns out, the niche has an important role in the behavior of these stem cells. Not only does it influence how often these stem cells divide, but also whether they retain what's called their 'stemness' - an inherent quality that allows them to stay less specialized themselves. The questions we are asking are: what are the signals from the niche that direct the stem cells to divide? How does the niche influence this 'stemness'? How are the maturation signals (that direct the formation of fully specialized circulating blood cells) warded off from the stem cells in the niche; and, also, by the niche?

The human niche of haematopoietic stem cells is the bone marrow. The bone marrow is the spongy part in the centre of some of our bones, like the bones at our hip and in our thigh. Studying the niche of haematopoietic stem cells within the marrows of people is not easy. In contrast, stem cells in flies are found in their lymph glands (blood forming organ). Knowing that the process of blood development in flies is very similar to humans, *Drosophila* thus becomes an attractive model to explore these questions that intrigue us.

### What is a typical day at work for you like?

I use the early hours of the day with my doctoral students. We discuss experiments they've performed the previous day and examine any hurdles that require trouble-shooting. We also meet once a week for more detailed discussions and brainstorming on individual projects.

**“While my profession has taught me to be logical, focused, and, to some extent, philosophical; my interactions with my kids after a long day’s work rejuvenates me!”**

Being part of one of the IISER system institutes, which offers (BSc/MSc integrated courses), I invest an hour and a half, every day, in teaching a class or preparing for one.

### What would you say are the most rewarding and frustrating aspects of being a biologist?

The most rewarding aspect is that I get to unravel phenomena that Nature has been concealing from us! In the words of a great biologist E.O. Wilson, “Our sense of wonder grows exponentially: the greater the knowledge, the deeper the mystery.”

There are two aspects of my work that bother me to some extent. The process of getting one’s work published can be frustrating - especially when you see your work being tossed from one academic journal to another, without peer review (the process of examination of a paper by your scientist colleagues in the same field, from anywhere in the world). The other big constraint to research is obtaining funds for one’s work. Not only does this directly affect the quality of your research, but it also slows you down scientifically.

### What are some of the most important benefits of your work to society?

As I’ve mentioned before, how blood cells are formed in our bodies is remarkably similar to that in fruit flies, both in the distinct phases of the process and the nature of signalling molecules that are crucial to it.

Very recently, my group identified ‘hubs’ of haematopoiesis in the fruit fly model system. These sites are simplified versions of a vertebrate bone marrow. We hope that this discovery will establish *Drosophila* haematopoiesis as a simpler, genetically testable model to separate out normal from abnormal blood cell development. This will open up endless possibilities in the future. The fruit fly haematopoiesis model can be used to help answer questions related not only to the formation of blood stem cells, but also to their migration and their roles in immunity, wound healing, ageing, and so on.

### How do your personal and professional lives influence each other?

I have always tried to balance my personal and professional life. While my profession has taught me to be logical, focused, and to some extent philosophical, my interactions with my kids after a long day’s work, rejuvenates me!

### What sparked off your interest in science?

I do not remember a specific time when I arrived at the decision to become a scientist. I have always been curious about the natural world. As a child, I remember spending many fun-filled afternoons, in the winter/summer school breaks, chasing insects or looking at birds, while my mother and grandmother were fast asleep. My love for science has kept me so focused on research that I have never considered any other career options.

Many people have nurtured my interest along the way. My parents have been a huge support system, and have helped me steer my course. My dad was my role model. Although he was a busy surgeon, he

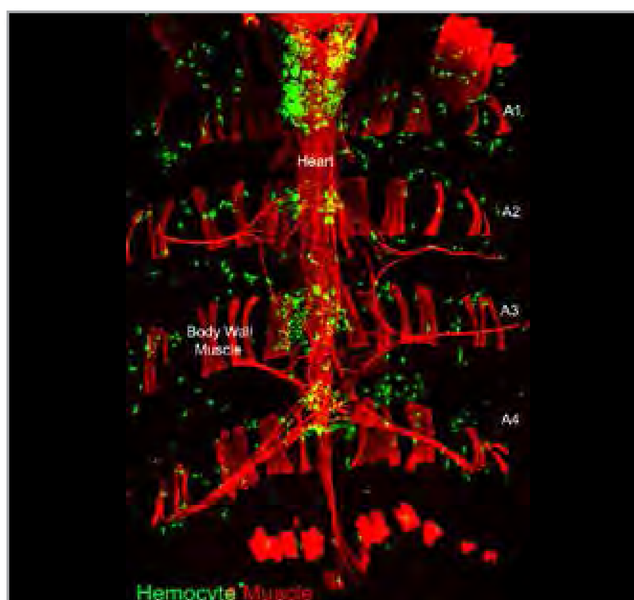



**Figure 1.** Haematopoietic hubs of the fruit fly: the simplest version of the vertebrate bone marrow. Haematopoietic hubs (green), containing discrete clusters of haemocytes, house progenitors and differentiated blood cells. In this image, they are seen tightly associated with fly heart muscles (red).

had a tremendous love for research. He was my first mentor—my interactions with him stimulated my scientific curiosity. In fact, it was he who inspired me to pursue a doctorate in science. My husband and brother have helped make all these years of work fun, and still keep me going!

My science teachers at school always encouraged me to ask questions, even though I would often use this opportunity to pester them with my endless curiosity. In those 'pre-internet days', we depended almost entirely on teachers and parents to guide us. But, somehow, I feel that our interactions with our teachers were warmer and more inspiring when we were not exposed to huge databases of information before we were ready for it.

During my postdoctoral studies at the University of California in Los Angeles (UCLA), I was lucky to have two fantastic scientists, Professor Volker Hartenstein and Professor Utpal Banerjee as my mentors. It was they who introduced me to my current field of work - *Drosophila* haematopoiesis.

### How did you come to choose haematopoiesis in *Drosophila* as the area of your research?

My doctoral work with Prof Jagat Roy at the Cytogenetic Laboratory, Department of Zoology, Banaras Hindu University (BHU), was focussed on studying the role of a tumour suppressor gene in brain tumours in fruit flies. I started studying neurobiology to understand normal brain development, but fell in love with the subject.

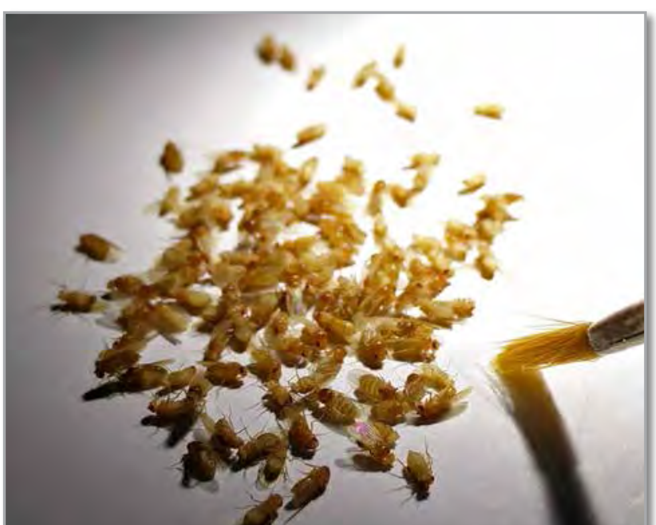


**Figure 2.** Fruit flies – the Cinderella of Genetics.

> Neil Armstrong once said, "Mystery creates wonder and wonder is the basis of man's desire to understand.

For my post-doctoral studies, I chose to join Prof. Volker Hartenstein (UCLA), who happens to be a pioneer in fly brain development. One day, after about three weeks of being in his lab, Prof. Hartenstein stopped by my working bench, and commented on how he thought that it was during post-doctoral work that one must take risks. I was puzzled by his comment and asked him why he was saying this to me. He responded with a smile, saying, "Do something that you have never done...there is fun in doing so....." He added that while the fruit fly is famous as a model for studying immunity, its feasibility as a model for studying the developmental aspects of blood cells was still in its infancy. He would like his students to explore this aspect of fruit flies. Like Prof. Volker, Prof. Utpal too had a tremendous interest in following this field of research. The first milestone paper on blood cell genesis was, in fact, published from Prof. Utpal's lab. It seemed like there was still a lot in this field that was left to be unravelled.... So there you go - I left neurobiology, and engaged myself in pursuing the development of blood cells in fruit flies.

### Are there any character traits that are a natural fit for scientific research?

Students showing curiosity, motivation, a commitment and eagerness to excel, and of course diligence, are a good fit for life as a researcher.

### How important are observation and wonder in science education?

A key element that drives research is your capacity to observe. Observing a phenomena or an experiment has a profound effect on a young mind. If we hope to infect students with an enduring interest in science, we must provide opportunities for students to observe textbook concepts in action.

The astronaut Neil Armstrong once said, "Mystery creates wonder and wonder is the basis of man's desire to understand". As also beautifully pointed out by Erwin Chargaff, "It is the sense of mystery that, in my opinion, drives the true scientist; the same blind force, blindly seeing, deafly hearing, unconsciously remembering, that drives the larva into the butterfly. If [the scientist] has not experienced, at least a few times in his life, this cold shudder down his spine, this confrontation with an immense invisible face whose breath moves him to tears, he is not a scientist." I fully agree with Armstrong and Chargaff's views on the importance of wonder in science. School science must provide opportunities for students to be awe-struck with the wonders of the natural world, and leaving them curious to unfold the mysteries that they observe.

### Can you tell us some things that you think teachers could do to encourage an interest in science?

Teachers have to be the bridge between textbooks and students. I mean this in the literal sense - to instil interest in the topic, we have to be the proactive link that infuses life and our own excitement into textbook content. Instead of telling students facts straight from a book, teachers may need to involve students in the process of discovering science through experiments, or engaging with a movie or story about a discovery or discoverer.

### How can researchers contribute to school science?

Researchers can inspire and fuel aspirations of eager students. Short interactive sessions with scientists can provide opportunities for the students to not only discuss the latest in science, but also get a feel for the real world of research. Another way researchers can engage with school science is by hosting students in their labs during school summer/winter breaks.

**Figure 3.** Dr. Mandal at work.

Instead of telling students facts straight from a book; teachers may need to involve students in the process of discovering science through experiments, or engaging with a movie or story about a discovery or discoverer.

IISERs (Indian Institute of Science Education and Research – a new series of institutes similar to the IITs) have 'outreach programs' that reach out to school students on a regular basis. There are five of these in India: apart from the one at Mohali, there are ones at Pune, Bhopal, Kolkata and Thiruvananthapuram. Another place that interested schools can visit is the Homi Bhabha Centre for Science Education (Mumbai).

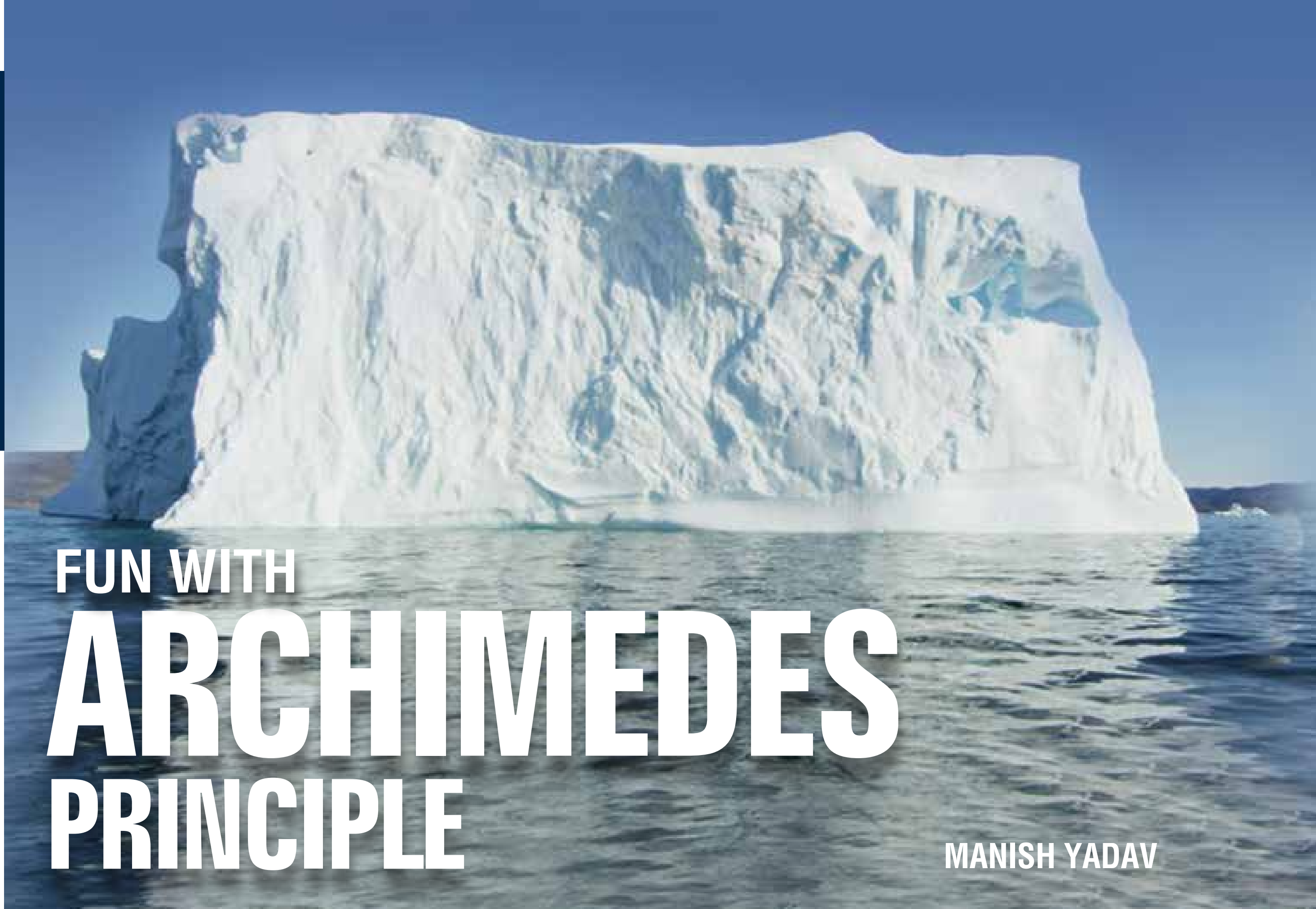
### What are some of the biggest misconceptions that school students and teachers may have about a career in science?

While it is true that it takes time to establish oneself in a scientific career, what I think may be important to remember is that a career in science does not have to be boring, draining, or poorly paid. If you have passion for science, you will enjoy the ebbs and tides of a research career.

### In what ways is the practice of science as a profession evolving? And, what fields will take centre-stage in the next few decades?

A career in science today is no longer restricted to becoming an educator or Professor. We find science students adopting a range of careers - from hard-core research (in academic as well as industrial organisations) to science communication and journalism, management, and even law (related to Intellectual Property Rights and Patents). Journalists with a strong background in science can help communicate the latest in scientific research to the common man. Those who also have a flair for English can help write scientific papers. A patent lawyer with a scientific background can help steer a researcher through dilemmas of 'what and what not to patent'.

Armed with multidisciplinary approaches, new technologies, and high-end instrumentation, current researchers can reach new heights and realise things that were previously unappreciated. Therefore, predicting which fields will rule the next decade is quite difficult at this point.



# FUN WITH ARCHIMEDES PRINCIPLE

MANISH YADAV

This article presents the journey of a group of science teachers in exploring Archimedes principle, and related concepts, through well-loved fables like that of the Thirsty Crow, as well as a series of simple, open-ended experiments with readily available material.

Although most teachers agree on the need for experiments in the teaching and learning of Physics, experimentation in schools often consists of students being asked to follow a series of instructions so as to arrive at a predetermined result or verify a previously stated law. This approach is aimed more at getting predictable results rather than encouraging students to use experiments to explore questions themselves. This is perhaps one of the reasons why teachers see very little value in conducting experiments in their classrooms. How, then, do we rethink the kind of experiments we use to teach physics in school? In this article, we use Archimedes principle to explore answers to this question.

## Activity 1: The Thirsty Crow and Archimedes Principle

Many of us have heard of the story of the thirsty crow that used pebbles to drink water from a clay pot. But have you ever attempted to verify this story? What role does the initial level of water in the pot have on the crow's chances of reaching it? Instead of dropping many small pebbles, what if we were to gently drop one big stone into the pot? What else (marbles, vegetable pieces, etc.) can be dropped into the pot to get to the water in it? What conclusion can we draw from this investigation? Would it be accurate to say that the water level rises to the brim only if the pot is filled with sufficient water to start with? Is this 'sufficient' water level half or two-thirds of the volume of the pot?

**Thirsty Crow Story**

One hot summer day, a thirsty crow was searching for water. After much searching, it found a pot with some water in it. The crow tried to push its head into the pot, but couldn't reach the water in it. It then tried to tilt the pot so that some water would flow out, but the pot was too heavy for it. Looking around, the crow spotted many small pebbles.

It used its beak to drop each of these pebbles, one-by one, into the pot. The water level rose. The crow drank this water and flew away happily.

**Figure 1.** Verifying the thirsty crow story: Teachers from the 'Let's do Physics' module, Training workshop, Nawai Dec 3-4, 2012.
Source: Azim Premji Foundation, Tonk team.

As you can see, this simple story can help us begin an exploration of the Archimedes principle. Imagine yourself to be a science teacher conducting this experiment in the physics classroom - you will most likely see a lot of happy faces discussing the water level and pebbles. We did this activity with science teachers, and as you can see in Fig. 2, they had a lot of fun searching for answers to these questions.

It is important to engage students in a discussion once they finish this activity. Teachers can use questions like, 'can we drop Thermocol pieces to raise the water level' to draw their attention towards sinking and floating properties of different materials.

## Activity 2: Factors that influence floatation

The floating or sinking of an object in a liquid depends on both the properties of the object as well as the properties of the liquid in which the object is dropped.

**Process:** Best performed as a group activity. Ask students to predict whether a particular object will float or sink in each of the three liquids provided, based on prior experience or through assumptions. Encourage them to think of floatation in terms of both the properties of the object they drop into these tumblers, as well as the properties of the liquids within these tumblers. Once they have made their predictions, ask them to test their predictions by dropping different objects into the liquids given to them.

**Sinking or floating:** You can ask students a variety of questions to get them to think more deeply about floating and sinking properties of objects and their relationship with properties of liquids into which they are dropped. Examples of such questions include – 'did you find any objects that float in all three liquids? Is there a reason why an object that sinks in glycerol, sinks in alcohol and water too? Why does this object sink/float in all three liquids? A crushed Aluminium foil is floating in water - could you think of a way to make it sink?'

This activity naturally leads to our next question - 'what are the properties of the objects or the liquids that influence floatation?' For simplicity, let us first consider only one kind of liquid, like water, and the

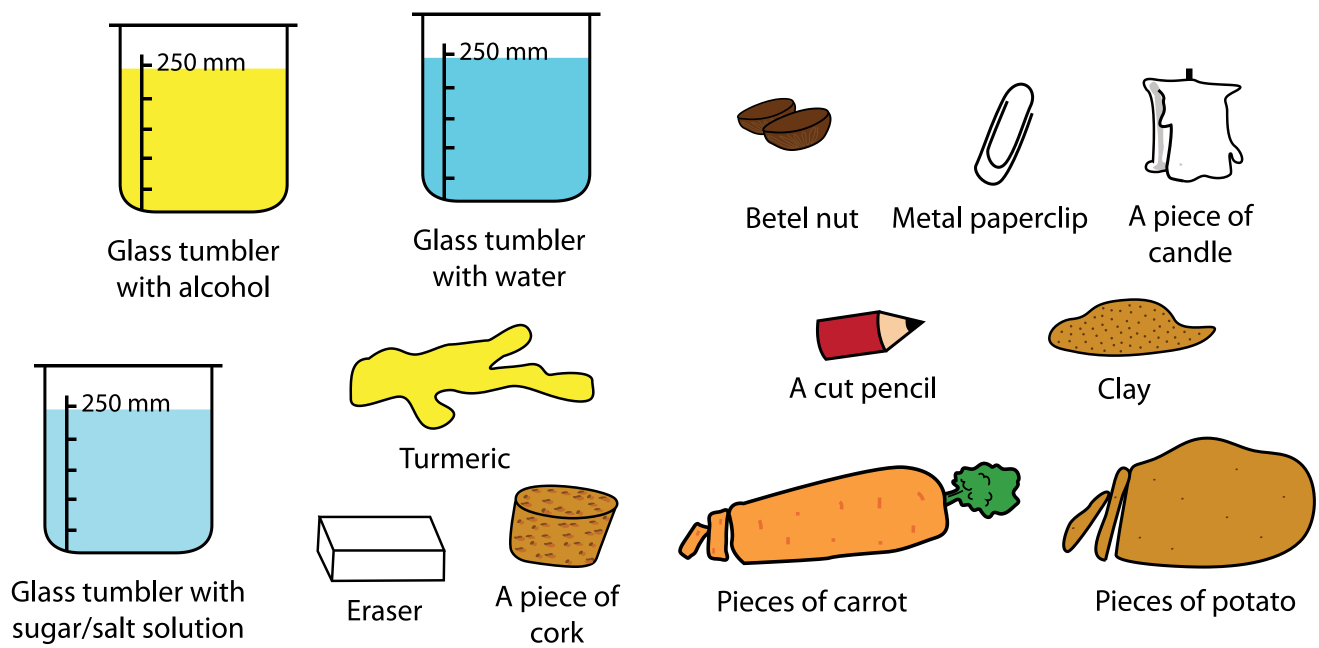



**Figure 2. Required Resources for Activity 2.** 3 glass tumblers (each with a volume of 250ml) - one filled with alcohol, a second with water, and a third with a sugar/salt solution. A piece of cork, an eraser, turmeric, betelnut, a metal paperclip, a piece of candle, a cut-pencil piece, some clay, and some pieces of carrot and potato.

> There is no rule about the set of objects chosen for this experiment. They've been chosen because they display different conditions of floatation in different liquids. Teachers can choose to have an entirely different set of objects that fulfil this same broad condition.

different kind of objects floating in it. Students at the school level will most likely answer this question by mentioning concepts like mass, volume, density, area, etc. You may also get responses like colour or length. Selecting objects that vary widely in colour and length in Activity 1 can be used to demonstrate that these properties have no connection with floatation.

## Activity 3: Exploring the relationship between the volume of objects and the liquid they displace

> The displaced volume of liquid is equal to the volume of the object within the liquid.

**Process:** Ask students to calculate the volume of the cuboids and spheres by making the necessary measurements and using the appropriate mathematical formulae. Once they've finished doing this, ask students to drop these objects one-by-one into the water in the measuring jar. By marking the level of water in the measuring jar before and after each of objects are dropped into it, students can calculate the volume of water displaced in each case.

Compare these values with the volumes calculated at the beginning of this experiment.

Some observations typical of this experiment are given below:

a. The volume of sunken objects is equal to the volume of the liquid it displaces.

b. The volume of floating objects is greater than the volume of the liquid it displaces.

These observations can be expressed mathematically:

$V_{object} = V_{liquid}$ displaced when object sinks.

$V_{object} > V_{liquid}$ displaced when object floats.

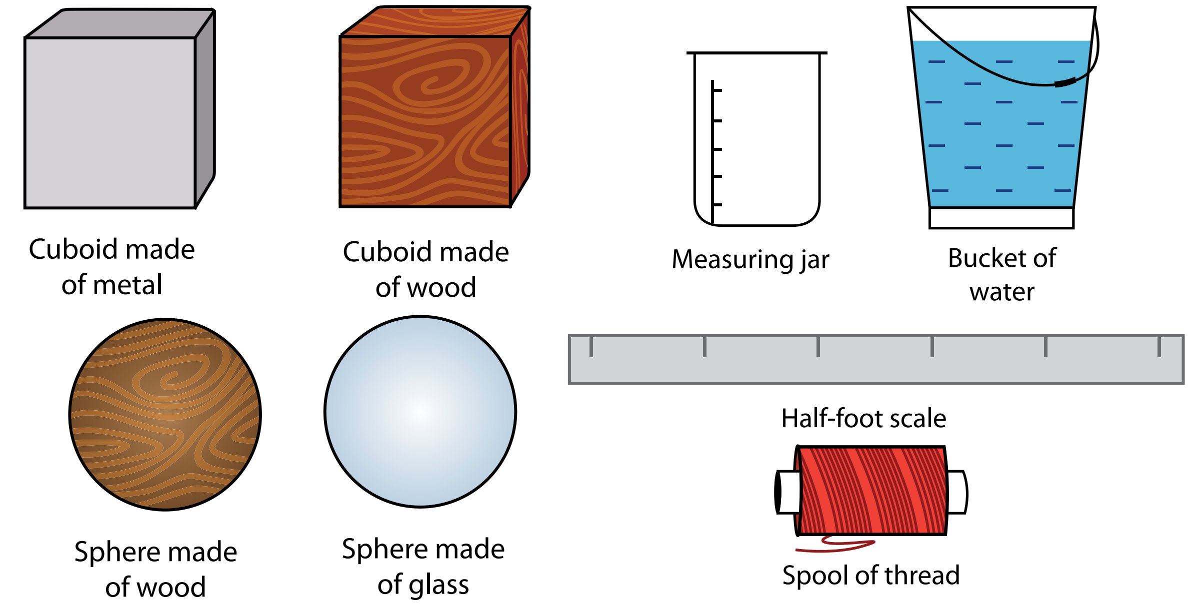



**Figure 3. Required Resources for Activity 3.** 2 cuboids (one made of iron and the other of wood), 2 big spheres (one made of wood, the other of glass), a measuring jar, a spool of thread, a bucket of water and a half-foot scale to measure the dimensions of the cuboids.

## Activity 4: Exploring the relationship of mass and density in floatation and sinking

**Process:** Ask students to calculate the mass and volume of the cuboids by making the necessary measurements and using the appropriate mathematical formulae. Then ask them to dip the cuboids one-by-one in water kept in a measuring jar, and record the mass and volume of displaced water in each case. Encourage them to use these observations to explore the relationship between mass, volume and density; especially given the fact that objects of the same volume can show different floatation properties (while one floats, another may sink). After they've finished doing this, you can also ask students to test this relationship with objects of irregular shape. This will help them arrive at a relationship like this:

Here $V_o$ stands for the volume of the object and $V_w$ for the volume of water displaced. Similarly, $D_o$ stands for the density of the object, while $D_w$ stands for the density of the water displaced.

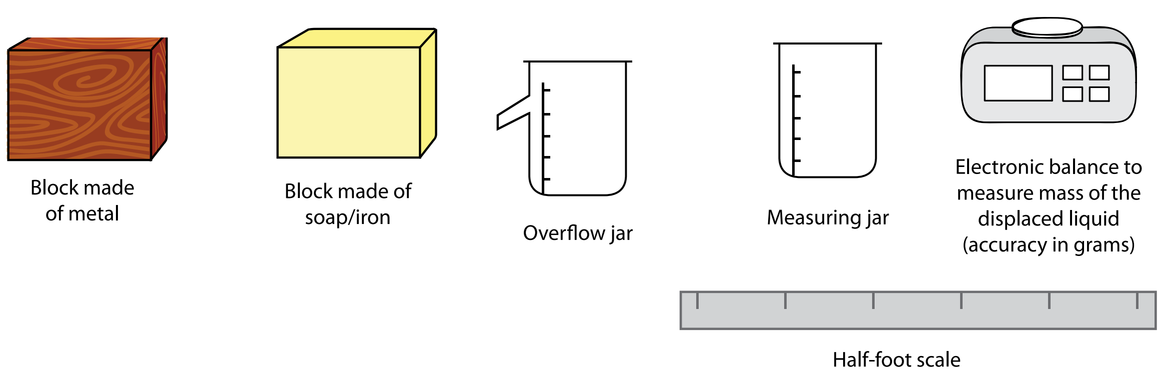



**Figure 4. Required Resources for Activity 4.** A block of wood and a block of soap/iron of the same dimensions (identical except for the material), an overflow jar, a measuring jar, an electronic balance to measure mass of the displaced liquid (accuracy in grams), and a half-foot scale to measure the dimensions of the cuboids.

| | Volume Relation | Mass Relation | Density Relation (Mass / Volume) |
|---|---|---|---|
| Sink | $V_o = V_w$ | $M_o > M_w$ | $D_o > D_w$ |
| Float | $V_o > V_w$ | $M_o = M_w$ | $D_o < D_w$ |

Will the results of this experiment be different if the density of the object is the same as the density of the liquid in which it is dropped? You can explore this question by dropping carrot pieces first in water, and then in a saturated solution of citric acid/ sugar solution at room temperature.

Once we explore the properties of objects, with reference to floatation, in one liquid (water), we can easily extend it to other kinds of liquids, like, alcohol, water, citric acid, salt solution and sugar solution. Ask students to think of how it is possible that the same object can float (partially or fully) and sink in different liquids. This is important to establish the fact that floating and sinking do NOT depend upon object properties alone. A simple demonstration of this fact can be seen using an egg in salt water (or carrot in citric acid). When we drop an egg into a jug of tap water, it will sink. By adding salt to tap water, the egg can be made to float as the density of saltwater is more than that of tap water.

Objects float on the surface of liquids of higher density, or below the surface of liquids of equal density. They sink in liquids with a density lower than their own.

This may lead to another question – 'Does the shape of an object have any role to play in flotation? Give students some clay/aluminium foil and a tub of water. Use different shapes made out of clay/aluminium foil, leading to different contact areas, to compare the different volumes of water displaced by them. This can lead to a discussion about how the shape of boats and ships are designed for floating, despite being made of material with a density much higher than seawater.

## Conclusion

These are just some ideas for experiments that can be used to explore a concept in Physics in ways that make its teaching and learning more engaging. This kind of approach provides students with the opportunity to 'explore' and 'discover' physical concepts themselves, and through such experiences, begin to construct their own knowledge. We tried out these ideas with 35 Government teachers (Nawai, Rajasthan), and received very strong positive feedback. Wouldn't you want to try them out in class too?


## Acknowledgement

I would like to thank my colleagues Rakesh Tewary and Ganesh Jeeva (co-developer of the module 'Let's do physics'). I would also like to thank Azim Premji Foundation Jaipur state and Tonk teams for their help in organising the training workshop 'Let's do Physics' at Nawai, in December 2012.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Let students ask and investigate:

# THE CASE OF A VARIEGATED PLANT

GURINDER SINGH &
KAREN HAYDOCK

What if teachers were to provide interesting but also confusing contexts to students? Would it encourage students to ask questions, and do their own investigations? In this article, the authors present an example of how a plant with variegated leaves provoked students to conduct a series of investigations to satisfy their own curiousity about the natural world.

Who asks most of the questions in a classroom - students or the teacher? In many cases, it is the teacher who does most of the questioning. And what kind of questions does a teacher ask? Questions for which the teacher already knows the answers! Students in schools are trained to give these answers, and are assessed for their ability to do so. Even if they do ask questions, students are expected to only ask 'textbook' questions that lie within their school curriculum. Such questions are inauthentic as they do not arise from the inquirer's genuine curiosity to 'know'.

When do people ask authentic questions? When we genuinely need to know about something; or when a gap or conflict arises between what we observe and our existing knowledge schema. We all ask authentic questions in our day-to-day lives, especially when we have a problem to solve. For example, we may ask other people waiting at a bus station if they know which bus you should take to get to the city centre; seeing a large number of policemen on the roads, we may ask ourselves or others around what's going on; when cooking more dal than usual in a pressure cooker, we may ask ourselves how many whistles will be enough to ensure that it is cooked properly. We constantly interact with our surroundings; and ask questions in order to understand, and in some cases, solve problems.

Why, then, do students not ask authentic questions in class? One reason could be that they rarely get a chance to directly interact with the natural world. Instead, students are largely engaged in the passive process of understanding the world indirectly through books and their teachers. Will opportunities to directly interact with the natural world provoke students to ask authentic questions?

In an attempt to find out, we organized a three-day workshop with a group of eleven Class VII students (ages 11-13) in which we took the students to a garden with a variegated 'bhendi' (*Talipariti tiliaceum*) tree (refer Fig. 1). This ornamental shrub has some green leaves, some leaves with asymmetric green and white areas, and some leaves that are completely white.

We know that middle-school science students are familiar with statements like:

- **Plants make their own food by a process called photosynthesis.**
- **Leaves are green because they contain a green pigment (chlorophyll).**
- **Photosynthesis cannot occur without chlorophyll.**

Given these statements, how does a white leaf, which does not appear to have chlorophyll, make its own food? And, if it cannot make its own food, then how does it survive?

This was the question that came to our own minds when we first saw this plant. We had other questions too. Do white leaves have some green pigments? Do white leaves grow at the same rate as green leaves? Do white leaves get their food from green leaves? We have been doing research to investigate how we can teach students science by encouraging them to ask questions and answer them by planning and conducting their own investigations. Thus what we were interested in seeing during the workshop was whether students would ask some of these questions too. And if they did, would they also be able to think of ways to investigate the answers to these questions.

We decided not to say anything - just bring the students near the tree. To our surprise, students in the workshop spontaneously started talking to each other and asking themselves questions about the tree. These questions were on a variety of aspects, including the colours, shapes and sizes of new, old and fallen leaves, thorns, and flowers etc. All their questions were recorded and displayed on a board. Students worked in small groups, discussing ways of investigating these questions. Each group planned and conducted their investigations with minimal help from us.

**Figure 1.** A variegated Bhendi (Talipariti tiliaceum) shrub - about 2.5 metres high. Credits: Gurinder Singh.

In this article we describe different activities that arose from this project. Some of these activities were performed by us prior to the workshop; others were planned and performed by students to answer their own questions. We do not expect these activities to be replicated in the step-by-step manner in which they are described here. Our purpose is to share some examples to show how students used the context of variegated leaves to generate questions and conduct scientific investigations.

## Is chlorophyll necessary for plant growth?

An activity which is sometimes done in school in order "to prove that chlorophyll is required for photosynthesis" is to take a variegated leaf, remove its green pigment by dissolving it in alcohol, and show that only the areas which were formerly green test positive for starch. However, this is a rather tedious procedure, and it actually does not prove that chlorophyll is required for photosynthesis, or even that photosynthesis is occurring. It merely indicates that only the green areas contain starch. It may even lead students to ask questions like, "Why does a potato, which is not green - also contain starch?" Is the potato also capable of carrying out photosynthesis? We can also question whether starch is an indicator of photosynthesis.

**Figure 2.** Compare some of the different kinds of leaves of the variegated Bhendi (*Talipariti tiliaceum*) shrub. Credits: Karen Haydock.

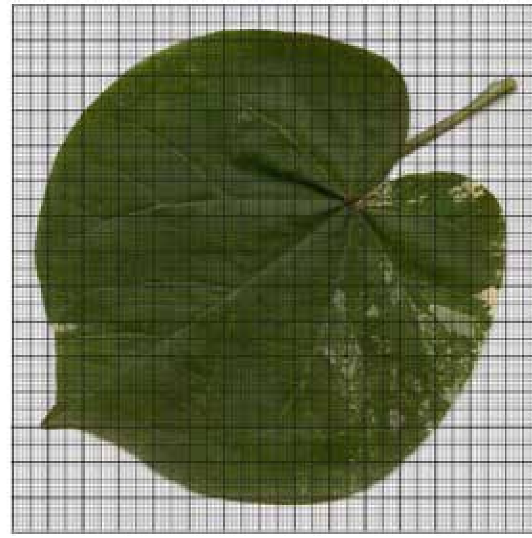

**Figure 3.** Measuring the surface area of a leaf using a graph paper. Credits: Karen Haydock.

We found some very simple ways to use variegated leaves to investigate the relationship between the presence of green pigment and food production, assuming that more food will result in more growth. This can be done by asking whether white leaves, or white parts of leaves (as shown, for example, in Fig. 2), have stunted growth.

One hypothesis that we had was that white leaves would be stunted because they contain less chlorophyll, which is essential for photosynthesis to occur. An alternate hypothesis was that the white leaves, or the white parts of leaves, would not be stunted because of a dense network of veins, which could carry food from one part of a leaf to another or from green to white leaves. To investigate these hypotheses the following activities could be useful.

**1. Are white leaves smaller than green leaves?**

This question can be investigated by selecting representative samples of white and green leaves, and measuring their sizes.

Students can devise various ways of comparing leaf sizes: with or without a scale or using graph paper to measure surface areas (refer Fig. 3). This activity is suitable for students of classes VI to X, and is a good way to integrate science and mathematics. It also motivates students to devise ways to measure the surface area of odd shaped objects.

**2. Does a plant have fewer white leaves than green leaves?**

If the plant being studied is small, it may be possible to count all of its leaves - this is appropriate for middle-school students. The alternative is that students may need to devise some sort of sampling method – an activity that may be a good exercise for students of classes XI and XII. This method will require learning and using some methods of statistics.

The presence of very few mature but many immature white leaves might indicate that green leaves survive better than white leaves.

**3. Are the white halves of a leaf smaller than its green halves?**

This question can be answered without even plucking any leaves from the plant. Students can simply fold each leaf in half along the midrib, and observe which side is larger (refer Fig. 4).

**Figure 4.** Comparing the relative size of the white vs. green halves of a variegated leaf. Credits: Karen Haydock.

This is an easy activity, even for students of classes IV or V. We tried this out by testing dozens of leaves of variegated Bhendi and could not find a single leaf in which the half that clearly contained more white was as large as the half which contained more green, suggesting that growth of the white parts of leaves is stunted.

We also noticed that bulges on the margins of variegated leaves corresponded to green areas (refer Fig. 5), supporting the conclusion that the intervening white areas have stunted growth. It would be interesting to see whether these observations hold for other variegated plants too.

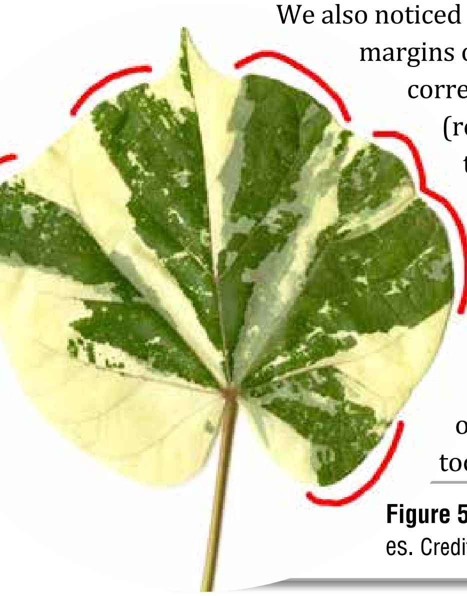

**Figure 5:** A variegated leaf with bulges. Credits: Karen Haydock.

**4. Do white leaves weigh less than green ones?**

In order to answer this question, we searched for green and white leaves of the same size (which was slightly difficult), and weighed them on an electronic balance. To our surprise, we found that some green leaves weighed considerably less than a white leaf of the same size. However, after the same leaves were dried, the white ones usually weighed less than the green ones. This indicated that perhaps the white leaves are producing - or at least storing - less food. Or perhaps the green parts produce more cells or more bulk.

**5. Are white leaves thinner than green leaves?**

This question was investigated by three girls who participated in the workshop (see Fig. 6).

They devised their own method to answer this question, estimating the thickness of leaves by feeling them. Each student would take turns to stand with her eyes closed and both her hands outstretched. Her companions would place a green leaf in one of these outstretched hands, and a white leaf in the other hand. The student with the closed eyes would feel the two leaves and call out the leaf that they thought was thinner. Each girl tested fifteen different pairs of mostly green and mostly white leaves (the same pair of leaves was not tested by more than one person). The three girls recorded the results of this experiment in a table. They reported that white leaves were thinner than green leaves in eleven cases (as they had expected based on their initial observations), and appeared to be of the same thickness in two cases. In another two cases, green leaves appeared to be thinner than white leaves. In one of these cases, they noticed that the green leaf was a lighter (brighter and yellower) shade of green, compared to a thick dark green leaf nearby. It was also much more flimsy. Although it was quite a large leaf, it was probably immature. Based on this investigation, the girls concluded that in general, the white leaves of the Bhendi plant are thinner than the green ones, perhaps because they are not able to make enough food for themselves, and/or do not get enough food from other leaves on the plant.

**6. Do white leaves wilt faster than green leaves?**

In the same workshop, a group of four 13-year-old boys noticed limp and shriveled white leaves on a branch that had been left overnight in a glass of water. In contrast, green leaves on the same branch had remained 'healthy' (turgid, actually).

**Figure 6.** Feeling leaves. Credits: Karen Haydock.

The boys therefore hypothesized that white leaves are not as healthy as green leaves, because they cannot make their own food and they rely on food provided by green leaves. They tested this by comparing branches with only green leaves, only white leaves, and mixed green and white leaves. They placed one of each type of branch in water and left it overnight. They also put one of each type in soil and left these overnight, after watering the soil (see Fig. 7). The next day, they were overjoyed to find that the branch of white leaves which they had put in soil had in fact become much limper than the branch of green leaves; while the branch of white and green leaves was somewhere in between these two in appearance (refer images on the left panel of Fig. 8a, b). However, what puzzled them was that they found that the reverse was true of the branches they had put in water (refer images in the right panel of Fig. 8c, d).

**Figure 7.** Boys putting branches in soil.
Credits: Gurinder Singh.

**Figure 8a and 8b:** Branches in soil: before and after. Credits: Karen Haydock.

**Figure 8c and 8d:** Branches in water: before and after. Credits: Karen Haydock.

**Resources**

For more information on variegated leaves, see the general botany section of the website of the Mildred E Mathias Botanical Garden, based at University of California, Los Angeles, USA: http://tinyurl.com/qgpl6y2. You can also find out more about variegated plants on the Union County College website: http://tinyurl.com/p2m7vgq. For a library of images of variegated plant leaves, see: http://tinyurl.com/ojpu9rr.

However, they remembered that two of the bottles had been filled with cold water and the other with water at room temperature. Perhaps this had made a difference? This led to a discussion of variables and the importance of trying to keep all variables controlled except for the one that is being tested. This may be the first scientific experiment that these 13-year-old students had ever conducted themselves, and we were pleased to find they had brought up the problem of the additional variable (cold or warm water) without any prompting from us.

## Now it's your turn

What other questions could students explore using Bhendi or other variegated plants? You can try taking students to a garden or a place having a variegated plant and let them explore, talk, discuss, argue, play and experiment, telling them as little as possible, particularly when they start asking questions. They may need some facilitation while planning and conducting investigations.

The beauty of this approach is that you do not need to tell your students what to do, step by step. With limited guidance, even students who have never carried out experiments before can raise their own questions, devise their own methods, carry out and then refine their experiments.

**Alternatives to Bhendi**

Besides Bhendi, there are a number of other species of ornamental plants that can be used for similar investigations. Some of these are listed below:

Variegated gingko (*Gingko biloba* var.)

Variegated maples (*Acer davidii* Hansu suru, *Acer platanoides* variegatum)

*Aralia elata* 'Aureovariegata'

Clown fig (*Ficus aspera*)

Some varieties of *Caladium*

Some varieties of *Dracaena*

Some species of *Hosta*.

We obtained slightly different results in similar investigations with other variegated plant species. This makes our conclusions all the more interesting: perhaps not all variegated leaves show obviously stunted growth in white areas?

We hope this article inspires you to let your students raise their own authentic questions and answer them by conducting their own investigations!

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**Karen Haydock** is a faculty member at the same institute, and has been working in India since 1985 as a researcher, educationist, scientist, teacher, and artist, after completing her PhD in biophysics in the USA. Besides working with Gurinder on student questioning, her recent research has been on: (1) overlaps between the processes of doing art and science; (2) problems and solutions in learning about evolution; and (3) the question of whether farmers do science. She has illustrated and written numerous storybooks and textbooks, and has also worked extensively in areas of teacher education and the development of teaching methods and curricula. Karen can be contacted at haydock@gmail.com or www.khaydock.com.

# SUN WONDER!

## Non-trivial concepts through day-time astronomy experiments with self-constructed equipment

PRAJVAL SHASTRI

Our Sun is visible during school hours, as long as the sky is relatively cloudless. Equipment that we can easily construct ourselves can be used to conduct simple observations and make measurements related to the Sun, from which insights into the world of astronomy, the workings of the Sun, pin-hole cameras and imaging, can emerge. A few examples of these activities are described here, with pointers to external text and video resources.

### Astronomy is Inspirational, but....

Enchanting is the sight of the Milky Way on a moonless night. Mesmerising are the photographs of the distant universe, brought home to us via the Internet by powerful telescopes like **Hubble, Spitzer** and **Chandra.** The sky is accessible to everyone and is a 'universal laboratory'. However, school hours are nearly always during day-time. Combine this reality with the scourge of light pollution, and practical star gazing within regular school curricula is virtually ruled out - with one exception. Our nearest star, the Sun, can play 'laboratory' during school hours! Thus, learning science by doing and discovering can indeed happen with day-time astronomy experiments.

**Cautionary Note** [1]

The Sun should not be stared at directly - it could harm our eyes. The projection of the Sun's image described in the activities below is one of the safe methods of viewing the Sun.

## Activity 1: Find the Day-time Moon!

**Materials needed:** A notebook for recording observations.

**Conditions:** Need to be out in the open with a fair part of the sky, including the Sun and the Moon visible, at least off and on, i.e., a relatively clear sky.

**Background:** Our Moon appears to shine brightly in the sky because it is lit up by the Sun. Since the Moon orbits around the earth once every 29 days or so, different parts of this illuminated side of the Moon are visible to us on different days, which we call 'Phases of the Moon'. Another effect of the Moon's orbit around the earth being once every several days is that, the Moon is sometimes visible at night, and some times during the day. Indeed the Moon is bright enough to be seen clearly against even the bright blue day-time sky. Finding the day-time Moon is an activity that can be a precursor to more in-depth activities that teach lunar orbits, eclipses etc. using models, or observations during day as well as night.

**Observational activity:**

1. Locate the Moon in the day-time sky.
2. What is its shape? Note down the rough shape in your log book with the date and time of observation.
3. What is the orientation of its shape w.r.t. the horizon/sky-line directly below it?
4. What is its location in the sky relative to the Sun? (South-East? North West?).
5. Point one straight arm at the Sun and another at the Moon. What is the approximate angle made by your arms?
6. Follow the path of the Moon in the sky by observing it at intervals of about 30-60 minutes, and repeat observations.
7. Repeat these observations over subsequent days.
8. Using the lunar orbit diagram in Figure 1, can you explain your observations over a period of a few days?

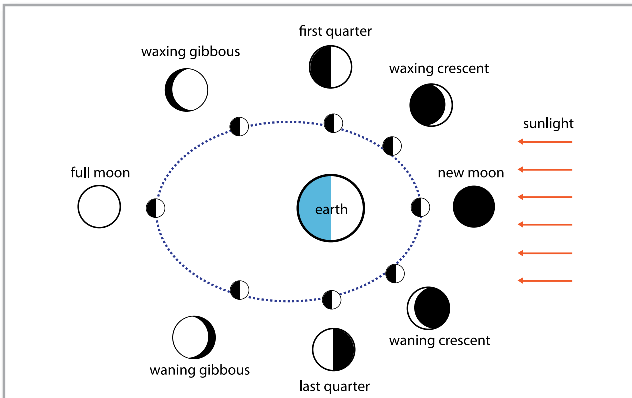

**Figure 1.** Lunar Orbit.

Note: The Moon will be visible in the mornings a few days after full Moon and in the afternoons a few days before full Moon. Be sure to arrange the first of these observations when the Moon is visible along with the Sun. Ideally, the observations should be continued through the lunar cycle so that the days when the Moon is not visible in the day-time sky are also noted. Students can then be encouraged to make observations during the day as well as night (at home) and relate their results to the explanation for the phases of the Moon that they study from their textbooks. Prior scheduling and planning of the activity can be done using lunar calendars, which are readily available on the internet[2].

| Observing site | Date | Time | Sky condition | Angle between Sun and Moon | Shape of the Moon |
|---|---|---|---|---|---|
| School Playground | Sun 20 Mar 16 | 13:00 | Clear | | |
| School Playground | Mon 21 Mar 16 | 15:00 | Partially cloudy | | |
| Local Park | Sun 20 Mar 16 | 11:00 | Partially cloudy | | |
| School Playground | Wed 23 Mar 16 | 11:30 | Mostly clear, passing clouds | | |

**Table 1.** An example of an observation template that can be used to track the moon.

## Activity 2: A Magic Mirror

**Materials needed:** A plane mirror of size about 3cm x 3cm; thick black paper of size about 15cm x 15cm (the size depends on the size of the mirror you have - see the instructions); a circular coin; a pair of scissors; adhesive; a small ruler; measuring tape; a notebook for recording observations.

**Conditions required:** Skies clear enough for the Sun to be visible (at least off and on) and an open area with not too much of the sky obstructed.

**Construction of the magic mirror:**

**Step 1:** From each corner of the black paper, cut out a square piece of size 5cm x 5cm with the cuts parallel to the edges of the paper, so as to leave a piece shaped like a large 'plus' sign (see Figure 2).

**Step 2:** Cut out shapes of a square, a circle (using the coin to draw it), a star and an equilateral triangle from the outer square segments of the 'plus'. These shapes should be smaller than the size of the mirror.

**Step 3:** Fix the mirror onto the central square area of the 'plus' with adhesive.

**Step 4:** Fold each of the square segments with the cut-out shapes over the mirror, so that you have four flaps to act like masks on the mirror.

**The Magic Mirror is ready!**

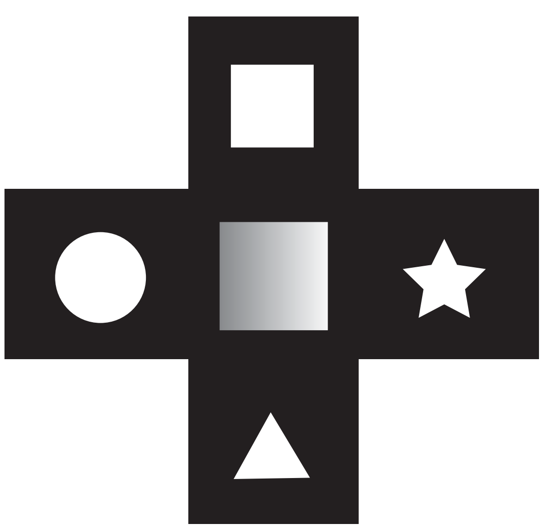

**Figure 2.** Black paper cut into a 'plus' shape, with the square mirror pasted in the centre; and shapes of a square, circle, star and triangle cut out of the four outer segments. Credits: Navnirmiti 2013.

**Usage:** Take the magic mirror outdoors to a spot where the Sun is visible. Hold the mirror out to 'catch the Sun' and experiment with the position and tilt of the mirror to reflect the bright patch of sunlight onto a nearby surface about a metre away. The surface could be a wall, a sheet of paper held by a friend, or the surface of a person's clothing.

Next, fold each of the flaps of the magic mirror over the mirror to cover it, and observe the effect on the shape of the bright patch. No surprises here: the shape of the bright patch will take the shape of the mask - whether square, circular, triangular or star-shaped.

Now for the surprise: increase the distance between the mirror and the projection surface to about 8-10 metres. If a person's clothing was used as the surface to project the bright patch made by the Sun, then the person's back should be turned towards the mirror to avoid accidental projection of the Sun onto her eyes, which could be blinding. Observe what happens to the shape of the bright patch. Regardless of the shape of the mask (whether square, circle, triangle or star), the patch is always circular! Fold the triangular mask onto the mirror, move the surface back and forth, and observe the bright patch change from triangular shape when nearby to circular when far away[3]. Repeat this for the square and star-shaped masks.

**Explanation:** The circular patch is the image of the Sun! This can be convincingly demonstrated by doing a similar experiment with light from a bright lamp, or a torch light, in a well-darkened room [4]. At a large enough distance from one of the walls of the dark room, the mirror projects an image of the lamp/ torch light. The idea of a pin-hole camera [5] has been known for centuries and has been extensively used to image scenery with large depth of field. Following the pin-hole idea, holes made in cardboard can be used to project an image of the Sun [4, 6 7]. 'Pin-holes' also occur in nature, e.g., the holes made by gaps between leaves of a tree [7]. The Magic Mirror behaves like the mirror-analogue of such a pin-hole when reasonably distant from the wall/screen of projection [8]. Even though the mirror is much larger than a 'pin-hole' as we think of it, what is key to the 'magic' is not the size of the hole/ mirror itself but the ratio between this size and the distance to the projecting screen, which should be large. The idea is expanded upon in the next activity.

## Activity 3: Ball-mounted Solar Projector

**Materials needed:** A medium-sized stiff plastic toy ball; some sand to fill the ball; a (used) ring of sticking tape, or a tennikoit ring, or a stable flat cylindrical container (without its lid and a diameter about half that of the ball) for the base of the mount; a small mirror (about 3cm x 3cm); a piece of stiff paper slightly larger than the mirror; sticking tape; a pair of scissors and paper cutter; a coin; a notebook for recording observations.

**Conditions for observations:** A reasonably clear sky with the Sun visible at least off and on.

### Construction of the Ball-mount and the Solar Projector:

Using the cutter, roughly mark four sides of a 2.5cm x 2.5cm square-shape on the ball and cut through three of the sides to create a square-shaped hole with a square 'flap' (see Figure 3). Use the hole to fill the ball with sand (somewhat more than half-full), which serves to weigh the ball down. Close the hole with the flap, and seal it off with sticky tape. Place this ball on the base of the mount (used ring of tape, or cylindrical container). You can feel that the ball can be rotated smoothly around on the base, but stays firmly in position when left alone.

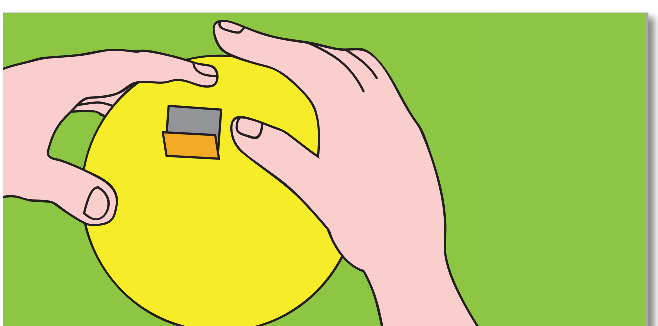

**Figure 3.** Cuts made on the ball using a cutter to create a square-shaped hole with a 'flap'. Credits: Suraj Zameen Par video series [9].

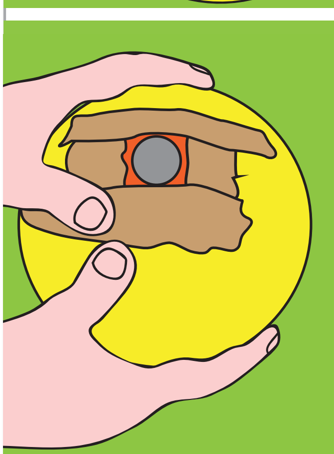

**Figure 4.** Mirror with a paper mask (circular hole) stuck firmly onto the ball. Credits: Suraj Zameen Par video series [3].

Using the coin, mark a circle of about 2 cm diameter in the centre of the stiff paper. Cut out this circle carefully and neatly to make a circular mask for the mirror. Apply some adhesive around the edge of the circular cut-out and stick the paper on the reflecting face of the mirror carefully, so that the cutout circle is roughly in the centre of the mirror. Make sure that no excess adhesive is left on the part of the mirror that is visible through the circular hole. Now paste the masked mirror carefully and firmly onto the ball using sticky tape. Make sure that the circular hole is not covered by the sticky tape.

### Your Solar Ball-mounted Projector is ready!

**Usage**: Place the ball projector on its mount at a spot on the ground outdoors. Experiment with rotating the ball and pointing the mirror so as to catch the Sun, and cast its image onto some vertical surface, such as a wall or a screen. Note that the further this surface is from the ball, larger is the image of the Sun, but lower is the brightness contrast, and, therefore, lower the visibility.

### Observational activities:

- How does the image change when you change the distance between the projected image and the projector?
- What happens to the image of the Sun with time (several minutes) if you keep the projector still?
- What is the direction of motion of the image with time (right or left? top or down? eastward or westward)?
- Manipulate the ball-mounted projector so that the Sun's image is thrown onto a wall inside a room (through its door, or a bar-less window). Observe the increase in contrast between the Sun's image and the surrounding area.
- If the room is further darkened using black curtains on its windows, ventilators and other openings, the contrast can be further enhanced.
- Mount a large sheet of light-coloured paper on the projected surface so that you can mark the shifts in the position of the Sun with time of day, day after day, etc., on the paper.
- Place the projector at exactly the same spot at the same time on the following day. What is the position of the Sun's image relative to the previous day?

- Can you see any dark splotches within the Sun's image? Do they move with respect to the edge of the image over time? These may be Sun spots[10]!

### Notes on the Equipment

**The mount:** The heavy weighed-down ball when mounted on a ring is not only very stable, but playing around with pointing it also gives the participant a feel for what is known in astronomy as the 'alt-az' or altitude-azimuth mount. This is one of the mounts used for astronomical ground-based telescopes, wherein mechanical drives enable circular movement of the telescope around two axes, the first of which is parallel to the ground (thus changing the tilt or altitude of the direction in which the telescope is pointing) and the second being perpendicular to the ground, which enables changing the 'azimuth' of the direction in which the telescope is pointing. All directions/points in the sky that are above the horizon are thus accessible to the telescope using a combination of these two independent movements.

**The projector:** The principle was introduced in the previous activity. The mirror masked by a circular hole behaves like a 'pin-hole' when the screen onto which the image of the Sun is projected is relatively far away. It is important to remember that (a) larger the size of the hole, further the screen needs to be for the pin-hole effect; (b) larger the hole, greater is the amount of light that is gathered (giving a brighter image) but also lower is the sharpness of the image (noticeable at the edge of the image or if there are Sunspots or a planet transit); (c) the further the screen is, the larger is the image of the Sun, but lower is the brightness contrast of the image relative to its surrounding area on the screen. There are thus some trade-offs, and the students should be encouraged to experiment with changing the size of the hole and the distance of the screen to identify these trade-offs themselves.

For the same distance between the mirror and the projection screen, placing the screen in a darkened room increases the brightness contrast between the image and its surrounding areas, thus enhancing clarity for the observer. The darkened room can be made to function as the data gathering studio with sheets of paper mounted on the projection wall for marking the Sun's position and movement. Once the projector has been played with, the other advantage of its design becomes apparent: regardless of the position of the Sun in the sky, the path from the projector to the screen can remain roughly parallel to the ground, which makes it very convenient.

**Figure 5.** Two children using a solar projector. Credits: Sejal Chevli and Navnirmiti Learning Foundation.

### Notes on the activities

Playing with different shapes and sizes for the mirror mask, and the distance of the projection screen brings home the idea of pin-hole projection. A mirror mask with a hole of about 2 cm diameter and a projection screen 30 metres away in a darkened room works well. Tracking and recording the movement of the Sun's projected image illustrates the daily, day-to-day and seasonal movements of the Sun with respect to us. Occasionally the surface of the Sun exhibits sunspots[11]. The ability to see sunspots requires reasonably large sunspots to be present and reasonably high sharpness of the image. Daily satellite images of the Sun, which show us whether or not discernible hotspots are visible, can be found on the NASA/SOHO website[10]. Sunspots are planet-sized regions on the Sun with very high magnetic fields and therefore higher magnetic pressure, which inhibit the convective heat from reaching the surface of the Sun. Hence these regions are slightly cooler, and therefore appear quite a bit darker, than the surrounding surface of the Sun.

## Conclusion

Astronomy is a delightful way to introduce things that are really faraway and **really** big, yet amenable to the laws of physics as we earthlings understand them. This introduction to our universe does not necessitate the night-sky and can be done with several day-time experiments during school hours, and can therefore be part of the school curriculum.

### Acknowledgements

The 'Magic Mirror' and 'Solar Ball Projector' were designed and developed by Navnirmiti, India, during Navnirmiti's Suntrek at Solar Maximum (2000), and the Transit of Venus Campaign (2004) respectively.

These and other daytime astronomy experiments are available on their website www.navnirmitilearning.org. The demonstration videos on **YouTube** of these and other daytime astronomy experiments have been produced by **Vigyan Prasar** in association with **Navnirmiti Learning Foundation** and **Bharat Gyan Vigyan Samiti**, Karnataka. The author acknowledges discussions over the years with the lead designers Vivek Monteiro and Geeta Mahashabde of **Navnirmiti Learning Foundation**.

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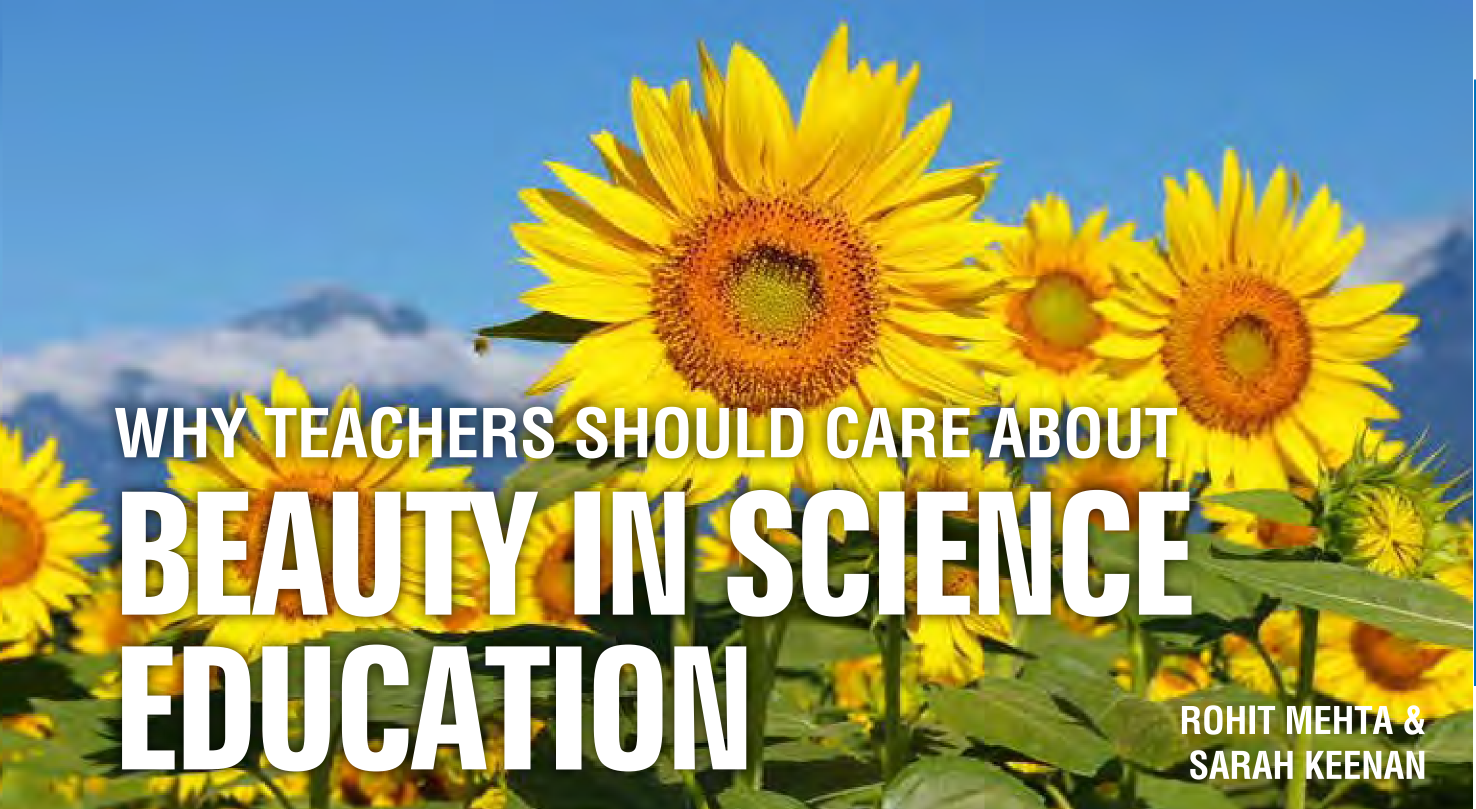

# WHY TEACHERS SHOULD CARE ABOUT BEAUTY IN SCIENCE EDUCATION

ROHIT MEHTA & SARAH KEENAN

This article explores the role of beauty in science education. The authors use research in science education to highlight the importance of teachers consciously making connections to aesthetic aspects in science. Caring about beauty in science can inspire a sense of wonder and curiosity among students.

> *"Horses and rainbows make the world seem more exciting, not science"*– student quoted in Mark Girod's dissertation research study
>
> *"He to whom the emotion is a stranger, who can no longer pause to wonder and stand wrapped in awe, is as good as dead – his eyes are closed."*
>
> – Albert Einstein

Scientists often speak of being inspired by wonder and a sense of beauty. They describe the universe with a sense of awe about it and our place in it, the drama in searching for the truth, and the elegance of scientific ideas and structures. Consider this quote by Richard Feynman:

The world looks so different after learning science. For example, trees are made of air, primarily. When they are burned, they go back to air, and in the flaming heat is released the flaming heat of the sun which was bound in to convert the air into tree, and in the ash is the small remnant of the part which did not come from air that came from the solid earth, instead. These are beautiful things, and the content of science is wonderfully full of them. They are very inspiring, and they can be used to inspire others.

Feynman highlights the potential of **wonder** and **inspiration** as he contemplates the world around him and the intricacies of its inner workings. This sense of wonder opens new doors and further questions to pursue; it is the beginning of a curiosity that inspires more questions. Science, he suggests, helps us find answers to some of the most awe-inspiring questions we have about nature. It is not a rigid method, or stuffed with facts and information that we need to memorize to pass an exam; but, rather, a rich and exciting process, an adventure and a journey to solve the mysteries of the world.

This sense of engagement and passion is often in stark contrast to how many students in school think about science. Science is often seen as being full of arbitrary facts, mindless activities and, thus, quite dull and boring (as seen in the quote at the beginning of this article). To be clear, we are not


**Figure 1.** Science is one of the most powerful ways to engage with the beauty of the universe. We use science to understand the cosmos and, in the process, find beauty in our understandings and representations of it. Credits: Illustration by Punya Mishra. Created with images under Creative Commons licenses, labeled for reuse with modification.

suggesting that scientific facts and theories are not important. Neither do we seek to imply that the scientific method is not rigorous and demanding, or, not in itself a reason that motivates some scientists. Our goal is to point out that what motivates scientists is not just the facts or the method per se, or instrumental reasons (such as economic viability), but also their passions that emerge from the excitement of the chase; the beauty, elegance and explanatory power of scientific ideas. The quote by Einstein, that opened this article, suggests that science is not a dispassionate activity. It is as much about facts as it is about wonder, passion, emotion, and beauty. This is what we call an **aesthetic** perspective.

## What does the research say?

What can we do to make science come alive for our students? How can we get them to appreciate the beauty and wonder of scientific ideas? What if we took some of these aesthetic elements that scientists speak of and bring them to the forefront of teaching science? What would happen then? Would students respond differently to what they were learning? Would their ideas of science, and what it means to **do** science, change?

One educational researcher, Mark Girod tried to find answers to these questions. He argued that the aesthetic experience is not just restricted to the arts, but is an integral part of doing and learning science as well. He suggested that by building on the emotional and affective elements of doing science, we could motivate our students to wonder more deeply about nature and science, stimulate their curiosity and interest, and thus transform their experience of learning science.

In his research, Mark studied two 4th grade science teachers. One of these teachers, Ms. Parker, was an experienced and accomplished teacher who taught science in the traditional way, focusing on facts and conceptual understanding. The other teacher, Mr. Smith, was also an experienced teacher, but with a different focus. Mr. Smith's class was designed to foster excitement and interest by organizing content around the power ideas have to inspire and renew perception, providing opportunities for students to experience the world in new ways that consistently highlighted the aesthetic and artful aspects of science. For example, conducting a class in a garden, while admiring the beauty of flowers, and framing questions that help explain, say, where a flower gets its color.

Mark's research showed that at the end of the day, students in Mr. Smith's class not only performed better than the students in Ms. Parker's class on standardized tests, but also showed greater engagement with scientific ideas speaking about how they had discussed these ideas with their family and friends outside of the classroom. In short, students in Mr. Smith's classroom were drawn to wonder, inspired to discuss it with others, and enjoyed seeing the world through the lens of scientific ideas.

## How can teachers cultivate an aesthetic classroom?

So what did Mr. Smith do in his classroom? While interested teachers may want to read Mark's study, we offer three suggestions that Mr. Smith successfully used in his classroom.

### Guide 1: Frame content around metaphoric ideas and perceptual lenses

While covering the topic of weather and the atmosphere, Mr. Smith did not just describe terminology and facts—he made them real through the use of powerful metaphors. For instance, he had his students lie down on the grass and look up at the sky – and told them about the ocean of air, 17 miles deep, pressing down on them. In other words, he shared powerful facts with his students: ideas of ways of looking at the world in an effort to generate a sense of wonderment. Lying on the grass looking at miles of vast sky and thinking of a metaphoric ocean stirred an aesthetic chord with Mr. Smith's students that a simple lecture could not.

**How to implement:** When thinking of a metaphor, make sure that you come with an idea that works on similar physical principles. It makes your work as a teacher more powerful when the transferability of the laws of physics makes the experience meaningful for your students. In this example, because air and water are both fluids, the metaphor makes conceptual sense and helps students understand and remember the ideas.

### Guide 2: Making it personal and learner-oriented

Mr. Smith constantly tried to empower his student to see and act with science in ways that fit them individually. He had them share science related stories from their lives prompted by questions such as "who thought about wind yesterday? What did you think about?" He pushed them also to 're-see' the world in new ways based on their learning of science. He also modeled for students how **he** saw the world through the lens of science – purposefully using words that demonstrated a connection between art and beauty and science. Even when using traditional worksheets, Mr. Smith included at least one question that allowed students to comment on their personal experiences with science content.

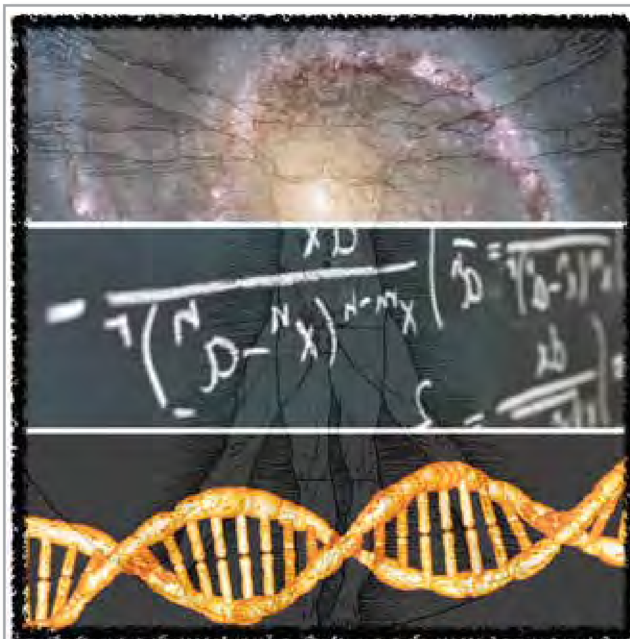

**Figure 2. Connecting across scales of beauty.** From the grandeur of the cosmos to the intricacies of sub-atomic particles, beauty is all around us. These infinities (of the very small and the very large) are bridged by the human intellect—the beauty of mathematics at work. Credits: Illustration by Punya Mishra. Created with images under Creative Commons licenses, labeled for reuse with modification.

Here, an aesthetic motivation can expand and enhance student experiences in science.

**How to implement:** A critical thing to consider is knowing what your students care about – getting to know their personal preferences and interests opens a window into their lives. You can then highlight those aspects of science that intersect with their lived experiences, in ways that they may have never thought of before. This makes the concept come alive in their minds, enriching daily life.

### Guide 3: Developing group activities that emphasize the aesthetic experience of learning science

Mr. Smith constructed a range of activities in his classroom designed to facilitate emerging aesthetic understanding and new ways of seeing the world. Students were asked to look at how artists use the sky to convey emotion, or to actually have them create artwork that attempted to capture similar ideas. He had them undertake 'fieldtrips'—short walks around school to observe science ideas learned in class. He had them make models from gumdrops and toothpicks as well as play with make-believe scenarios about upcoming weather events.

**How to implement:** Scientific ideas are powerful but, often, alien to us. Consider the vastness of space and the scale of the solar system. Making this scale realistic gives students an opportunity to aesthetically experience it and feel a sense of awe and wonder. Get your students to collaborate to calculate the relative distance of the planets from the Sun by embodying the solar system in your playground. Come up with a scale for distance and let one student be the sun, while other students become the planets. How far apart would they be? Is it even possible to go as far as Neptune or Pluto without leaving the school property? If one student becomes a beam of light, how long does it take to go from the Sun all the way to Neptune? And, then, imagine the next closest star being 4 light years away! Have your students attempt to visually and artistically represent these distances and scales.

## Conclusion

If science lets us perceive the world around us in new, transformative ways, then our job as teachers is to facilitate that re-visioning process. In fact, there is research to show that a teacher's beliefs about the nature of science are an important factor in how science is perceived by students. We need to step away from rigid curricula that focus only on success in tests, and, instead bring to our classrooms a sense of wonder and appreciation for the beauty of scientific ideas. We hope that the three broad suggestions here are just the beginning of many different ways in which science ideas can come alive in the minds and lives of our students.

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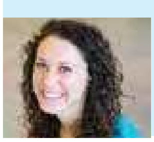


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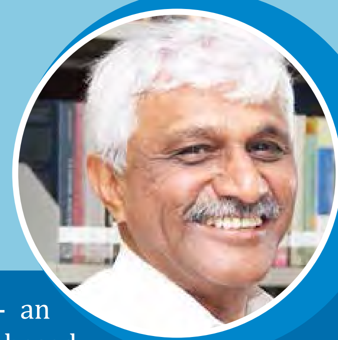
# INTERVIEW WITH RICHARD FERNANDES



Richard Fernandes co-founded Centre for Learning (CFL), Bangalore - an 'alternative' school, where he developed and implemented laboratory-based curricula for learning Physics. A strong believer in the dictum that "Physics is best learnt by doing", he enjoys building experimental apparatus from material found in scrap yards or cannibalized from discarded instruments. In this interview, he shares his experiences of being a Physics teacher at the middle and high school.

### Tell us something about your work as a science educator, especially at the middle-school level.

I set up a Physics teaching laboratory for students of the middle to higher secondary level, in a small, 'alternate' school that was started by a group of educators, including myself. The unique thing about the programme I set up was that experiment and theory were not two separate aspects of the subject. Classes were held in the laboratory and students hardly ever sat down to be 'taught'. They were on their feet doing things most of the time.

It did not take much money to set up this laboratory; most of the equipment was built by me using very rudimentary woodworking and machining skills and equipment. The main sources of material were the scrap shops and 'chor bazaars' around Bangalore. But that did not mean that the experiments were crude and unsophisticated. Using such simple equipment brought a sense of connection with the data collected or phenomenon studied. This is in contrast to the black box approach that is followed even in engineering education today where experiments are set up and sealed in a polished box by some manufacturer of scientific equipment and a prescription then given to get the experimental results.

### What made you want to become a science teacher?

The joy of sharing what I enjoy is probably the foremost. Other reasons include a missionary zeal to do my bit to get rid of superstition and obscurantism in society. I was strongly inspired by the work of the Nuffield Foundation, who developed one of the most comprehensive science and student friendly education programmes ever, and drew heavily on the material developed by them. However, I cannot see myself being a science teacher in the mainstream school system with its emphasis on content and the pressure to deliver it in a specified time.

### On a daily basis, how do you prepare for class?

I do not teach school-level science any more. When I did, preparing for a class meant getting apparatus out of cupboards and making sure that things were in working order. I generally had a lesson plan that I threw out of the window if the class took an interesting turn. This is a big advantage of not being weighed down by a syllabus.

### If one walked into your classroom on a typical day, what would they observe?

Students going through a set of instructions, written or verbal, setting up and doing a set of experiments, discussing the results of these experiments, drawing logical and not necessarily correct conclusions, and being guided by me to the desired conclusion if that was important. These activities are often boisterous and noisy, and much of my effort goes into preventing accidents.

### Do you have any advice for science teachers who might have big ideas for ways to get their students interested, but might not be sure how to implement them?

Early interest in Science is in wanting to know the how and why of the workings of things, both natural and human-made. Address those things that are accessible, be honest and logical, and do not give hand-waving reasons. I believe that remarks like "scientists have

> "Experiment and theory were not two separate aspects of learning Physics. Classes were held in the laboratory and students hardly ever sat down to be 'taught'. They were on their feet, doing things most of the time".

found" discourages students and puts them in awe of these 'scientists' and at best makes them want to be one of those scientists. On the other hand, tell them, "you are the scientist, make your discovery". The first approach makes them ambitious; the latter gives them the confidence that comes with achievement.

Do not make nationalism an agenda in science education. The Raman Effect is very hard for the average high school student to understand. Leave it alone.

### Is there something as a 'natural aptitude' for science? What is the role of a science educator in identifying and nurturing it?

This is dangerous territory for a teacher. I like to believe that all students are equally capable and I pay equal attention to all of them. Students get fired up by different things at different times. It would be wrong to judge students too early. Very often the more articulate and precocious students are identified as having a natural gift.

I have seen some students take to science more easily than others. A little detective work then leads to the fact that the reasons are more social than anything else; students are picking up stuff from their environment – a parent, older relative or friend.

The genius and the prodigy will always find a way to emerge. It is the average student that needs to be nurtured.

### What if your students don't 'get it'? In other words, if a lesson is not working for all your students, do you have a plan for remediation?

If students don't get it, try another approach. There are many ways to look at any problem.

### How important are specialist subject qualifications for effective science teachers?

In a perfect world, school science teachers would have research degrees in their respective disciplines. Not because researchers know more but because they develop the skill to tease out information out of what they study. This would enhance their ability to attempt many different approaches to help a student understand something. This is your answer to the ksjdgprevious question.

### How can a teacher motivate a student to read science articles outside school textbooks?

Informative posters, such as those brought out by National Geographic magazine, liberally distributed in the laboratory, encourage students to explore reading material in those topics.  Have articles lying around. Do not be too concerned about these being ruined by handling. Do not force anything; just an occasional suggestion is adequate. An open library with every spare bit of money being spent on popular science magazines is a big help. Let them see you reading; that inspires them to do the same.

### How important is it for middle school teachers to look at science without fragmentation into disciplines (physics, chemistry, biology)?

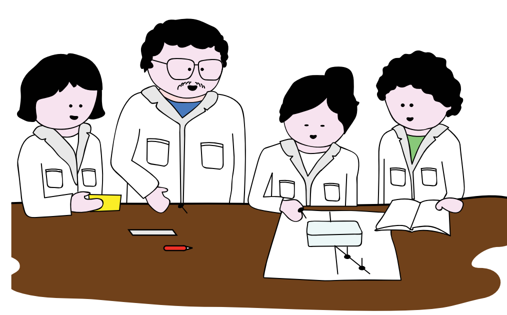
We learn various disciplines in a fragmented manner. This is out of convenience rather than the nature of the disciplines. Nature does not behave in this fashion. It is therefore necessary that teachers be aware of this; and not place excessive emphasis on this fragmentation in their classes.

### Describe a teaching method or strategy that is successful in helping students learn a concept in biology, chemistry, or physics?

Follow the scientific method: experiment, abstract, predict and test.

### Have you ever used differentiated instruction?

In the classroom situation, I have not provided any kind of differentiated instruction. Instead, I prefer to use more individualised assessments.



### What is the role of: a) experiments, b) computers, c) place-based experiences and d) story-telling in middle-school science teaching? What are you your experiences of these? How should a teacher introduce them in classrooms?

Without a doubt, experiments and place-based experiences are central to science teaching. We

> …remarks like "scientists have found" discourages students and puts them in awe of these "scientists" and at best makes them want to be one of those scientists. On the other hand, tell them, "you are the scientist, make your discovery". The first approach makes them ambitious; the latter gives them the confidence that comes with achievement".

should not teach science as a bunch of facts or a series of explanations of phenomena that are not seen easily by the student. We should encourage students to make observations about things around them, distil these observations, teach them to ask critical questions, and then do controlled experiments. I cannot imagine myself teaching science without getting students to do experiments. When you teach about density, measure the mass and volume of a brick, calculate its density and then use it to estimate the weight of the walls of the classroom or a truck load of mud. The immediacy that it brings is far more valuable than a dozen problems involving the application of density.

Computers are way over-rated and should not enter the science classroom unless a student actually wants to use it to control an experiment.

Anecdotes about discoveries and their discoverers are very valuable; the one about James Joule going on his honeymoon with a sensitive thermometer and measuring the temperature difference of water at the top of the waterfall and that at the bottom evokes giggles in a bunch of teenagers, but drives home an otherwise abstruse idea.

### How can teachers encourage greater participation by women in science and technology?

I would think that a teacher has to work on his/her prejudices, if any, on the ability of women to participate in the scientific workspace. If no prejudice exists, teachers will not discriminate between boys and girls in the classroom or laboratory. If there is prejudice, no amount of regulation will prevent it from being conveyed to the girls that they are not capable of being just as good as the boys.

### What would a science assessment in middle school look like if you designed it with learning as the goal?

When a young student learns science, the information s/he absorbs is fairly rudimentary and will undergo many refinements as s/he progresses through the educational system. On the other hand, the methods of observation have the same innate character and I would give far more importance to them. For these reasons, I place emphasis on formative assessments, and generally ignore any kind of summative assessment at the middle school level.

### Can competition be re-defined to function as a positive, non-stressful process?

I do not believe that competition can be a non-stressful process.

### What is the weirdest thing that you have ever done in the name of science?

I once sang loudly and in high falsetto into a microphone connected to an oscilloscope to demonstrate the frequency range of the voice. It led to considerable mirth (and annoyance) all around.

### What do you love most about being in the classroom and teaching middle school science?

I was schooled in the conventional way: stock questions with stock answers, concepts to be learned and problems to be solved; with no emphasis on observation and deduction.

Teaching middle school science brought me startling, yet natural, answers from students to common questions. This showed me that Physics was often counter-intuitive, and quite frequently changed my perspective on what I thought I knew well.

### What have been some of the moments/events/ memories of teaching that you cherish the most?

I once set a lab mock exam for students appearing for their higher secondary examination. It had to do with observing and listing the standing waves in a hack-saw blade excited with a variable-speed eccentrically loaded motor. The students were doing this experiment for the first time. The "Wow!" one of them excitedly yelled out when he saw the first stationary wave and the many such "Wows" from students when they see something that is 'mind blowing and awesome' is what makes up my most memorable moments in teaching science.

> "I generally had a lesson plan that I threw out of the window if the class took an interesting turn. This is a big advantage of not being weighed down by a syllabus".

### Do you have any advice for, say, students who realize they like science, or want to be a science teacher?

It can take a long time, and there is a lot to learn before you may get creative; just hang in there!

# THROUGH THE LOOKING GLASS

HARINI BARATH

The microscope is the mainstay of cutting edge research in many fields of biology today. When was it invented? What did the initial versions look like? What are some of the latest versions, and what can we use them for? This article provides glimpses into the history of microscopes before recounting some of its more recent and exciting developments.

*"Where the telescope ends, the microscope begins. Which of the two has the grander view?"*
—Victor Hugo, Book 3 Chap. 3 of Les Miserables.

Few of us can forget the first time we managed to make brick-like rows of cells, peppered with dots of cytoplasm, appear from a flimsy piece of stained onion peel after twiddling the wheels of a school microscope. An indispensable tool in many labs, the microscope is an instrument that helps us examine objects that are too small to be seen by our naked eye. This powerful invention has opened up the previously invisible world of cells and microorganisms to us. Even today, microscopes form the spine of many major areas of life science research, like cell biology.

**Figure 1.** Skin of a tomato as seen through a microscope. Source: Umberto Salvagnin. License: CC-BY. URL: https://www.flickr.com/photos/kaibara/7781208904/.

## A brief history

The first microscopes date back to the early 1600s. While it is not clear who the original inventor was, it is believed that the term 'microscope' was coined in 1625 by a friend of Galileo Galilei, a German doctor and botanist named Giovanni Faber[1]. In the years that followed, the microscope was increasingly used to examine and record biological structures. The most memorable contributions to the field of microscopy came about 50 years later, by Antonie van Leeuwenhoek, celebrated today as 'the father of microbiology'.

van Leeuwenhoek was originally a trader of drapes and linens. He became fascinated with lenses, which were commonly used as magnifying glasses to count threads, and soon mastered the art of lens-making. He made several hundred lenses and many different types of simple microscopes - small lenses mounted on brass plates - whose magnification far exceeded that of even the compound microscopes his contemporaries could craft. These state-of-the-art microscopes allowed van Leeuwenhoek to make ground-breaking observations. He was among the first people to observe cells; discover bacteria and protozoa; and study animal and plant tissues, as well as mineral crystals[3].

## Simple and compound microscopes

A simple microscope typically uses a single lens to magnify an object, much like a hand-held magnifying glass used for reading. van Leeuwenhoek's microscopes were among the best simple microscopes ever made, achieving magnifications of more than 250X. This meant that the image was more than 250 times the size of the sample being viewed. It was more than a century before compound microscopes were able to better this.

### Suggested exercise

Give students a magnifying glass and allow them some time to find out, by themselves, how to use it most effectively. They can use a page of their textbooks to experiment. Tell them to look through it first with both eyes open, and then with one eye closed. They can also try holding the magnifying glass at various distances from their eyes. Many will find that closing the non-viewing eye and holding the magnifying glass about half a foot away from the open eye gives the clearest image. Stress that everybody uses it differently and each student should find out what works best for them.

Stick a large leaf on a sheet of white paper and mount it on a board. Ask students to start by holding the magnifying glass very close to the sheet, and slowly moving it further away, stopping at every step, and observing how the image changes. Ask them to draw what they see at 3 or 5 different distances (e.g. 6 inches, 1 foot, 2 feet, 5 feet) from the board in their notebooks. Students can use a measuring tape to measure this distance from the board. They should try to reproduce the detail and size of the image in the magnifying glass as closely as they can.

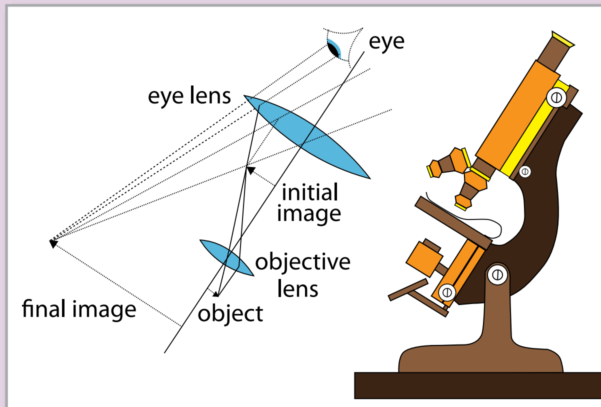



**Figure 2.** Lens/ray diagram that shows how a compound microscope produces an enlarged, but inverted, image of the object. Source: school physics.co.uk. URL: http://www.schoolphysics.co.uk/age16-19/Optics/Optical%20instruments/text/Microscope_/index.html.

A compound microscope has more than one lens, connected by a tube. The lens closest to the sample is called the objective. The image made by the objective is further enlarged by the eyepiece - the final lens through which the viewer sees the magnified image. Modern microscopes are all compound microscopes. They boast significantly higher (about 1000X or more) magnifications than a magnifying glass.

### Suggested exercise

Dip a toothpick into curd/yogurt and use this to smear a very small drop of this liquid onto a glass slide. Gently place a coverslip on top of this smear. View under a compound microscope, slowly increasing its magnification. You will be able to see small bacteria, singly or in clusters, and in different shapes - rods or spheres. Encourage students to reproduce what they see through the microscopes in their notebooks[2].

## Collaborating with artists

Modern microscopes record their images on computers, and previously on film, so researchers can do without the good drawing skills that are often considered necessary for recording and note-taking in school biology. But what did researchers in the 17th and 18th centuries do? Images were published as engravings. To do this, a drawing was traced onto and carved or etched into a copper plate, which was then printed.

Robert Hooke, a contemporary of van Leeuwenhoek, and author of **Micrographia** - the first scientific bestseller, made his own illustrations. His book contains the first microscopic images of plants and insects. van Leeuwenhoek, however, was not as skilled, and therefore worked with artists who would make the images for him. An engraver would engrave and print the plates[4].

**Figure 3.** Life magnified: A human liver cell. Source: National Institute of General Medical Sciences. URL: https://www.nigms.nih.gov/education/life-magnified/Pages/1b3_human-hepatocyte.aspx.

Microscopy continues to bring scientists and artists together, even today. Many artists and photographers are inspired by the compelling images captured by powerful modern microscopes. Their interactions with scientists often result in a collection of stunning images, some of which make their way to art exhibits, and others to public spaces like airports, where they serve as an eye-catching way of popularising science[5].

Today's researchers are trying to zoom much further into the cell. They seek to probe and photograph the wheels and cogs of all living systems – the biomolecules. One invaluable technique that has made this possible is fluorescence microscopy. Biochemists have discovered a whole host of fluorescing molecules - proteins that spontaneously emit light of one colour after being excited by light of another colour. By chemically coupling these labels or markers to other proteins of interest that do not emit light of their own, researchers are able to 'see' proteins as they move and interact with each other.

Optical microscopes are limited by what is known as the 'diffraction limit', which only allows them to discern details larger than half the wavelength of light, almost of the order of microns. So, two spots, which are less than a micron apart, will appear as one spot. However, a full understanding of many key bimolecular functions, processes and diseases requires a nano-scale picture. Researchers have developed ingenious ways to overcome this constraint and capture the nano-world. These 'super-resolution fluorescence microscopy' methods work by controlling the fluorescent labels in different ways. In fact, the 2014 Nobel Prize in Chemistry was awarded to Eric Betzig, W.E. Moerner and Stefan Hell for the development of these techniques.

## Electron microscopes

All the microscopes discussed in this article are optical microscopes - they use light to generate an image. There are also other types of microscopes, including scanning probe microscopes, ultra microscopes and electron microscopes.

Ernst Ruska and Max Knoll are credited with creating the first electron microscope in 1932. As its name suggests, electron microscopes use electrons instead of light to form an image. Glass lenses are replaced by electromagnets, but the working principle remains the same as an optical microscope. Electrons have a much shorter wavelength than light. This means that the electron microscope can resolve, or reveal details on a much smaller scale than an optical microscope. In fact, the best electron microscopes can tell two atoms apart! Electron microscopes can also achieve significantly higher magnifications – almost a thousand times better than a compound microscope.

Studying biological samples in an electron microscope, however, has one major problem. Samples are studied in a vacuum, and need to be prepared or 'fixed' by one of many methods. This means that live cells cannot be viewed or photographed.

## Making better microscopes - an ongoing quest

Even after three centuries of pioneering work that have made microscopes tremendously powerful and sophisticated, there is room for improvement. "As a physicist, I think there is a huge amount of physics left to be explored and exploited in microscopy," says G. V.

Pavan Kumar, Assistant Professor in the Department of Physics at IISER, Pune. His work is a continuation of the legacy of the many physicists before him whose efforts, through the ages, have helped overcome the limitations of microscopes.

Biological samples are largely transparent. Staining these samples with contrast agents is one way to make them visible under the microscope. But this means that the specimens need to be killed and fixed before staining. Is there a way we can look at living cells instead? Transparent samples, that don't affect the amplitude of light rays, diffract it. But they also modify another parameter imperceptible to our eye, and called its phase. The Dutch mathematician and physicist, Frits Zernike, discovered a method to convert these phase changes into contrasts in intensity. Using a special disk and a phase plate, he separated and increased the phase difference between direct light and the light diffracted by a specimen. The subsequent interference of the separated light waves resulted in an amplitude contrast that is visible to the human eye.

Until recently, phase-contrast was a qualitative method to see cells and tissues non-invasively. Efforts are now focused on extracting quantitative information from the phase change, with scientists trying out several experimental approaches to achieve this. Pavan Kumar and his colleagues are currently dabbling with one such state-of-the-art technique, which could benefit both material science and biology. They have technology that can tailor a phase pattern into the light shone on the sample. The diffracted light, whose phase is modified by the sample, is compared with a reference beam by interference. The phase difference information between the two beams of light is then extracted. A very accurate image of the sample can be constructed using this information, with details of cellular structures and motions on a nanometer scale. "Among other things, this is a method of label-free imaging, which has great advantages in biology," says Kumar.

### Foldscope

Microscopes don't come cheap. Or they didn't, until now. A paper microscope called the Foldscope (https://indiabioscience.org/columns/indiabioscience-blog/foldscope-events-in-india-the-delhi-photoblog), developed by Manu Prakash, a biophysicist at Stanford University, is set to change the status quo. This origami-based microscope, which can be printed and assembled from a sheet of paper, costs about a hundred rupees. Yet, it provides a magnification of over 2000X, weighs less than a 1 rupee coin, and doesn't need an external power source to work[6].

### What is phase?

Waves are defined by several properties. It is easy to understand some of these properties by generating a wave on a long string of rope tied at one end. The amplitude is simply the height of the wave - wiggling the string harder makes waves of larger amplitude. Wiggling it faster, on the other hand, increases the frequency of the wave. Phase is another property of a wave, but it cannot be perceived easily. Perhaps the easiest way of understanding it this - when the crests and troughs of two waves are lined up, they are said to have the same phase. If they don't line up, the distance ('theta', measured in angles) between the two crests is the phase difference between the two waves. In a sense, the phase of a wave defines its starting point.

When light passes through any object, its phase changes; some objects alter this phase (or delay the light, in a manner of speaking) more than others. Very cleverly taking advantage of this, phase contrast imaging techniques allow us to look more clearly at biological samples that are transparent to light, or very similar to the background.

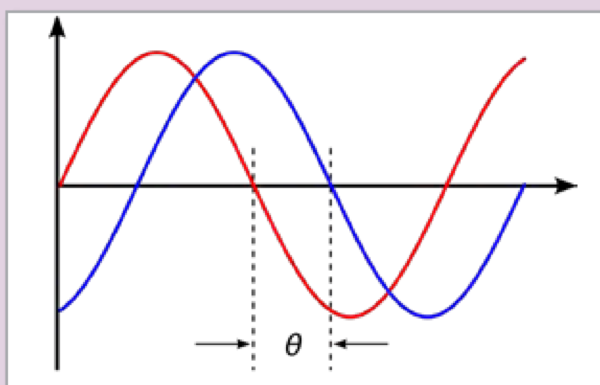



**Figure 4.** Two sine waves offset from each other by a phase shift. Source: Peppergrower (own work), Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Phase_(waves)#/media/File:Phase_shift.svg. License: CC-BY-SA.

The on-going quest for nano-scale clarity has many takers - maybe not among drapers anymore; but, certainly from chemists, physicists and engineers, among others. Their efforts will go a long way in furthering our understanding of the wonderful mechanisms of biology, and hopefully, give us ways to correct those that go wrong. Biology, however, is not merely a muse for innovators. After all, it has been experimenting with the nano-world eons longer than us and has learnt a trick or two, which we can only hope to mimic.

**Additional readings/resources**

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# IGNITING CURIOSITY IN YOUNG MINDS WITH THE FLAME CHALLENGE

REETEKA SUD

A curious 11-year old boy walks up to his teacher to ask, "What is a flame? What's going on in there?" After a brief pause, the teacher replies, "Oxidation". Factually speaking, the teacher was right on point, but the student felt deflated, wondering if there's more to explaining the science behind something other than giving it a different name! The kid in this story grew up to be the famed Hollywood actor and director, Alan Alda. He never forgot this instance of having asked his teacher a question about a flame; or her abrupt answer, devoid of any elaboration. In fact, this experience from his childhood became the inspiration for a contest he started for scientists, aptly called 'the Flame Challenge'[1].

*"Clarity in communicating science is at the very heart of science itself. And I wondered if written and oral communication skills could be taught systematically throughout the entire length of a student's science education"* — Alan Alda.

Since it was started in 2012, the Flame Challenge has become an extraordinary learning experience for children, who are integral to the whole process — from submitting their questions to selecting winning entries to the challenge question. The question for each year's challenge is picked from questions sent in by children themselves. There aren't any restrictions on what can, and cannot be asked; the point after all is to stoke their curiosity. The organisers scan through all the questions submitted to identify a common theme. For instance, the question for the Flame Challenge in 2014, "What is colour?", was selected based on student questions that year as — "Does everyone see colour the same?"; the classic "Why is the sky blue?", and a variant of that, "Is my blue also their blue?". Through the process of coming up with questions, kids have a chance to wonder, and express, what it is they want to know about the world around them.

Once the selected question is announced, any scientist can take a shot at answering it— keeping a typical 11 year old in mind. Submissions from scientists take the form of written entries or video recordings/animations.

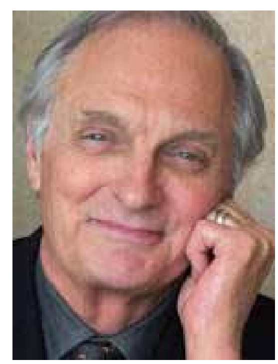

**Figure 1.** Alan Alda. Alan Alda Centre for Communicating Science, Stony Brook, NY. URL: http://www.alanalda.com/alan_alda_flame_challenge.htm.

Entries are judged by 10-12 year old students from schools in 19 countries (and counting). Each class typically gets at least five entries to judge. Students discuss the merits of each entry before rating it on the basis of how much they learned from it, whether the answers were interesting and clear (or boring and confusing), and whether they sparked an interest in learning more about the subject. All the student–judges then vote for winners in written and video categories. Winning entries are chosen for being both informative and engaging.

The teacher is an important part of this process. Other than registering their students as judges2, teachers also facilitate the voting process for their respective classes. The entries are sent directly to the registered teacher, who then distributes it among her students in whatever manner she sees fit. Again, it is the teacher who submits the results from student voting to the organisers.

**Figure 2.** Flame Challenge 2016 – What is Sound? Alan Alda Centre for Communicating Science, Stony Brook, NY.

**Figure 3.** Students judging submitted entries. Alan Alda Centre for Communicating Science, Stony Brook, NY. URL: http://www.centerforcommunicatingscience.org/student-judging-photos/.

Flame Challenge:
http://www.centerforcommunicatingscience.org/flame-challenge-2015/

Class registration for judging entries to the 'Flame Challenge 2016' question:
http://www.centerforcommunicatingscience.org/the-flame-challenge-2/school-form/

FAQs for teachers:
http://www.centerforcommunicatingscience.org/faqs-for-teachers/

Instructions for teachers:
http://www.centerforcommunicatingscience.org/teacher-instructions/

As a teacher, you may find yourself wondering why you should tell **your** students about this. What's in it for them? Here's what Mr. Alda says in response to that: "Judging requires critical thinking, working together and synthesising knowledge," he said. Michelle Miller, a teacher at Selden Middle School, New York, shared her experience after her class's participation: "This experience provides such good analytic skills. They were not only reading for information but reading the entries in order to evaluate them. This propelled them to a higher level thinking skill immediately. They noticed when several scientists talked about the same piece of information. ... My students were invested in the results and were so excited that many of them picked the video winner. The repetition of the reading and video pieces was also an excellent learning tool and offered us an authentic reason to do close reading."

Have you found yourself in a situation where you've had all the facts but still found it difficult to explain something

Going on now is the registration of classes for judging this year's challenge question: What is sound?

to your students? Even a cursory glance through the winning entries quickly shows us the importance of choosing the right amount of detail and of using analogies in communicating science. For instance, the winning entry to explain sleep (Flame Challenge 2015) compared it to "a superpower, a TV with static, a brain-cleaning system". How wonderfully vivid! Similarly, the winning entry to explain colour (Flame Challenge 2014) explains it so: "Did you know that dogs don't see all the colours that we do? ….. Colour itself isn't a thing, like a pencil or a notebook. It is how our eyes interpret light reflected off of objects. That is why we cannot see colour in the dark — there is no light to reflect…."

Too much of science instruction involves providing students with the knowledge of established facts and having them apply this information to pre-defined problems (often replete with answers at the end of the textbook). Such a system breeds conformity, not curiosity! This is ironical because it goes contrary to what science is — it is not information; it is a way of making sense of the world around us.

Tens of thousands of kids from all over the world have excitedly delved into the mysteries of nature as they've judged the scientists' entries. For adults who try answering these very same questions, the idea is to test not how much they know but how effectively they can communicate this understanding to engage kids.

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## POLLINATORS OR PLANT MUNCHERS?

# THE BUTTERFLIES

GEETHA IYER

Butterflies have always been a source of beauty and wonder. But, what gives these lovely insects their attractive colours? What is the best time to watch them? What do we know about their behaviour? In this article, the author explores the fascinating world of butterflies, sharing some ideas to bring them to life in the science classroom.

From ancient to modern times, butterflies have had a deep impact on the minds of humans. On the one hand, they have been thought of as patron deities in the Aztec calendar, or soothing minstrels that lull you to peaceful sleep by bringing pleasant dreams. On the other, butterflies have been a source for scientific and (nano-) technological research, helping produce efficient light-emitting diodes or paints without toxic pigments. Over centuries, butterflies have shared a warm relationship with humans. Their beauty and colours have inspired poets and painters. Their frequent silent ethereal presence and their life cycle have led ancient cultures to look upon them as spirits of the deceased and modern day humans to welcome them with joy. Butterflies are insects, yet their relationship with humans is never negative. I often wonder whether they are even thought of as insects by humans.

Butterflies can be seen everywhere, even in urban areas, flying among auto-rickshaws, cars and motorbikes, and occasionally even resting on concrete roads. We read about deers and other small mammals being crushed under the wheels of speeding motorists; but, butterflies too are often victims of humans in a hurry. If we attempt to study butterflies more closely, we are likely to find that there are many interesting aspects of science that these insects can help us understand. For example, many concepts taught in physics and chemistry, including those dealing with colour, flight or pressure can become clearer through the observation of butterflies. This article is to help you connect with butterflies in your neighbourhood, as well as to explore some activities that will help your students learn scientific concepts in an interesting way. Welcome to the lepidopterist's world!

**Figure 1.** Caricature of a lepidopterist.

## Lepidoptera

Butterflies, and their more abundant cousins - the colourful Moths, belong to the order Lepidoptera. The word Lepidoptera comes from two Greek words – '*Lepis*' meaning scales and '*pteron*' meaning wings. The defining characteristic of Butterflies and Moths is the presence of scales on their wings, bodies and appendages. If you have ever had the opportunity to pick up a dead butterfly or even the discarded wing of a butterfly, you may have noticed that they leave some coloured dust on your fingers. These are the scales from their wings. These scales are modified hairs that are responsible for the colours observed in these insects.

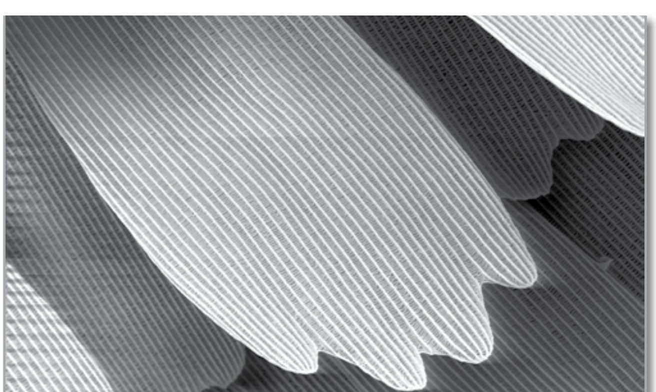

**Figure 2a.** Micrograph of butterfly scales. Source: SecretDisc, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:SEM_image_of_a_Peacock_wing,_slant_view_3.JPG#file.License: CC-BY-SA. Narayanswamy.

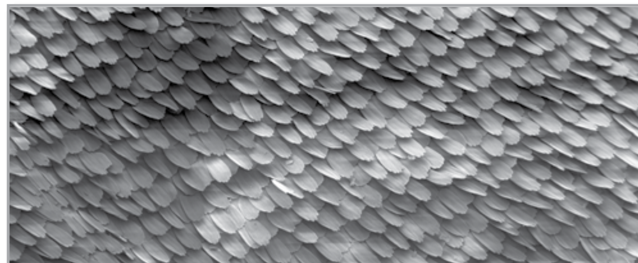

**Figure 2b.** Another view of micrograph of butterfly scales. Source: SecretDisc, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:SEM_image_of_a_Peacock_wing,_slant_view_1.JPG#/media/File:SEM_image_of_a_Peacock_wing,_slant_view_1.JPG. License: CC-BY-SA.

Butterflies share the general external characteristics of all insects - namely a body divided into a head, thorax and abdomen; three pairs of jointed appendages; a pair of wings; compound eyes, antennae and mouth-parts in the head. Of the four structures that make up the mouth-parts of an insect, it is parts of the maxillae that are modified to form the proboscis. This is the second most characteristic feature of butterflies – a long tubular proboscis that they use to sip nectar from flowers. The next time you see a butterfly alighting on a flower, observe it closely - you will see it extend a spring-like proboscis, which is usually kept coiled and tucked away under its head, into the corolla of the flower. Watching the coiling and uncoiling of the proboscis is quite a fascinating sight!

**Figure 3a.** Proboscis coiled up.

**Figure 3b.** Proboscis extended.

Butterflies are holometabolous insects – in other words, they undergo complete metamorphosis. Eggs hatch to form larvae, which grow to become caterpillars that continuously eat, grow and moult. These finally transform into an externally inactive pupa or chrysalis, which after a period of intensive internal transformations emerges as the adult butterfly. This gradual stepwise change in form and structure of a caterpillar to an adult is called metamorphosis. These stages are extremely significant; since some species of butterflies do not feed at all. The caterpillar is the only feeding stage in the lifetime of such species. The energy required for pupation, transformations and emergence of the adult butterfly, which then finds a mate, copulates and lays eggs, is all derived from what is stored in the body tissues during the caterpillar stage. One can therefore understand why caterpillars feed so voraciously and continuously.

> An activity that can be undertaken in classrooms is to discover how much a caterpillar eats, how much of it is (roughly) utilised and what amount discarded. Additional details are provided in the section on learning activities.

## Puddling

Puddling or mud puddling is one among the many interesting behaviours exhibited by butterflies (as well as moths and insects from several other groups). Puddling species often congregate in large numbers near puddles, wet patches, over carrion, bird and animal excreta, and even on human sweat.

**Figure 4a.** Palm Red-eye eggs. Source: Chitra Narayanaswamy.

**Figure 4b.** Palm Red-eye eggs ready to hatch. Source: Chitra Narayanswamy.

It is believed that a deficiency of sodium in adult butterflies triggers puddling. However, puddling is not a simple phenomenon of obtaining sodium. Puddling butterflies extract a variety of mineral salts - predominantly sodium, as well as certain amino acids, not obtained in adequate amounts from their regular diet. Research into this behaviour has shown that it is only males, especially young males that puddle. Why do females rarely mud puddle? And those that do are mostly older females. Several hypotheses have been put forward to explain this gender bias and need among young males. According to one hypothesis, the intense competition for nectar-feeding may have driven young males and older females to adopt alternate foraging strategies such as puddling for nutrients. According to another, males spend a lot more time flying than females. Since sodium is needed for neuromuscular activities, males may need more sodium. In many species, copulating males transfer sodium to females - sodium is necessary for egg production.

Is it possible to know whether butterflies actually sip fluids from a puddle? The best time to look for pudding butterflies is during the monsoons or post-monsoon season. You will see the gentle movement of the proboscis – a sign of puddling happening. If you observe these butterflies closely, you will notice that as they puddle, some of the fluids taken in are pumped out. You can see droplets of fluids coming out from the anus of the butterfly. In fact, when a butterfly wants its daily dose of mineral and can't find wet patches, it pumps out fluid from its anus onto a rock/stone/soil to wet it, and then extracts the mineral from this surface.

It's quite fascinating to observe mud-puddling. Although more frequently seen in Papilionids and Pierids, butterflies from other families also puddle. Lycaenids (blues) and Nymphalids are more often seen on sources other than wet soil patches for their daily dose of minerals.

**Figure 5a.** Butterfly sipping a cold sodium drink.

**Figure 5b.** Butterfly guzzling human sweat.

**Figure 6.** A butterfly pumping fluid on a rock.

## Recognising butterflies

Butterflies differ from each other in many ways. For example, the wing designs and colours of butterflies vary not only between species, but also between the upper- and under-sides of a single species. Thus, several of their features have to be observed carefully for the precise identification of a butterfly species. To help beginners ease into observing butterflies, what we provide in this article is a very simple and elementary family-level description of these insects. It really does not matter if you can't immediately start identifying different species. Continue to observe them using the pamphlet provided with this article. As you become increasingly familiar with the habits and behaviour of butterflies you observe, you will become better at identifying them.

Butterflies are grouped into five large families namely Papilionidae, Pieridae, Lycenidae, Nymphalidae and Hesperidae.

A) Family Papilionidae: Since the hind wings of many members are extended into a tail, butterflies of this family are generally referred to as Swallowtails. Not all Papilionids sport this feature. Close to 100+ species of Swallowtails are found in India. Since the underside of the wings of many of these butterflies is dull coloured, you may miss seeing them till they open their wings. However, the brilliant colours of the upper side will make you gasp in surprise and joy - such is their beauty! It is these brilliant colours that make them favourites with butterfly collectors, and hence these species are frequently smuggled. In fact, some rare ones, like the Bhutan Glory and Kaiser-i-Hind found in the North and North-eastern parts of our country, are fast becoming scarce due to excessive collection and habitat loss. Apollo, Helen, Mormon, Jay, Mime, Bluebottle, Gorgon, Swordtail, Dragon tail, Swallowtail, Peacock, Lime, Rose, Windmill, Spangle, Raven and Zebra are some of the fanciful common names of butterfly species from this family. Look out for their caterpillars on Citrus trees, Curry-leaf tree and Aristalochia; you will surely find them. A few species of this family are described below.

### Birdwings

The black and yellow Southern Birdwing, *Troides minos*, with a wing-span of 140-190 mm is endemic to the Western Ghats.

The female of this species is the largest butterfly of India. Two other species found in other regions of India are the Common and Golden Birdwing. All three species may be found in forested regions and are generally found flying above tree tops.

**Figure 8a.** Southern Birdwing. Source: Suresh Elamon.

**Figure 8b.** Common Birdwing (female).

**Figure 8c.** Golden Birdwing.

## Mormons

The second largest butterfly from India is also a swallow tail – the Blue Mormon *Papilio polymnestor*, which is not restricted to forests and therefore more visible than the birdwings. It is found frequenting gardens, especially post monsoon.

Common Mormons, like several other Papilionids, are great mimics. The female of the Common Mormon mimics two other Swallowtails - namely the Common Rose and the Crimson Rose. The Crimson Rose is avoided by birds because it accumulates bitter chemicals in its body. The Mormon, though, is much more palatable to birds and hence protects itself by mimicking the wing pattern of the Rose (see the attached pamphlet for images). You can tell the original one from the mimic by observing their body colour. Mormons are black bodied, whereas Roses are red-bodied butterflies.

**Figure 7a.** Five-bar Sword Tail

**Figure 7b.** Red Helen

**Figure 7c.** Tailed Jay

**Figure 9.** Blue Mormon.

B) Family Pieridae: This family of sun-loving butterflies are commonly referred to as whites and yellows, as these are colours that are often seen on their bodies. There is no one defining feature that can help identify a Pierid. Familiarity through observation of various features, such as the wing colour, patterns and venation, is the only way to know them. Like the Papilionids, the Pierids also mud puddle, much to the delight of lepidopterists who wish to observe them closely or photograph them. You can often see them basking in the sun with their wings open. Some members of this family, namely the Emigrants and Albatrosses, are seasonal migrants. Many members, such as the Common Jezebel, accumulate distasteful chemicals in their bodies, and thus avoid predation. Recent research has shown that the Great Orange Tip butterfly produces a neurotoxin similar in composition and effect to that produced by the Cone Snail found in our oceans. Scientists quote this as an example of convergent evolution where two completely dissimilar species seem to secrete a similar chemical. Grass yellow, the various coloured tips (Crimson tip, Orange tip, Yellow-orange tip etc.), Arab, Albatross, Puffin, Gull, Pioneer, Psyche, Cabbage white, Jezebel, Wanderer and Sawtooth are some examples of Pierids.

**Figure 10a.** Emigrant

**Figure 10b.** Grass Yellow

**Figure 10c.** Great Orange-tip

C) Family Lycaenidae: Many of these butterflies are unmistakable for the attractive shades of blue on their wings. Commonly called the Blues, Lycaenids make up the second largest family of butterflies. As many as 521 Lycaenid species are found in India and, like the Papilionids, consist of species with fancy names such as Coppers, Sapphire, Silverline, Royal, Imperial, Forget-me-not, Cupid, Cerulean, Pierrot, Flash, Quaker, Onyx, Yamfly, Apefly, Hairstreak and Gems. Male Lycaenids have only two pairs of functional legs. Their forelegs are reduced, with the tips being fused and without claws. The females do not possess this feature. Several blues have small hair-like extensions from their hind-wings, forming small tails, not similar to those seen in Papilionids. The lives of these butterflies are closely associated with ants. Some of their caterpillars feed on aphids and scales, while some caterpillars of other Lycaenid species produce a sweet fluid as a reward for the ants that protect them. The smallest butterfly from India, called the Grass Jewel, can be seen throughout the year fluttering at ground level among grasses. The second smallest butterfly, called the Tiny Grass Yellow, is also a blue and shares the habitat of the Grass Jewel.

**Figure 11a.** Metallic Cerulean UN

**Figure 11b.** Metallic Cerulean UP

**Figure 11c.** Tiny Grass Blue

**Figure 11d.** Red Pierrot

D) Family Nymphalidae: All butterflies of this group have a stunted, much reduced pair of forelegs covered by hair and looking like brushes. Commonly called brush-footed butterflies, Nymphalids make up the largest family of butterflies, containing an assorted list of species that were earlier categorised into other family groups. This group can be easily identified - look out for butterflies that stand on only four of their legs. The stunted fore-legs, held beneath the head, are too small to be of any use to the butterfly, which perches using only its remaining two pairs of legs. This feature is common to both males and females except in a group of Nymphalids called Beaks. The reason for this feature is yet to be thoroughly understood. The leading belief is that the hairy forelegs are used for a variety of behaviours that may be seen among this group. These butterflies show wide variations in shape, design and colour at all stages of their lives - eggs, larvae, caterpillar, pupa to adult. The Monarch, famous milkweed butterfly whose migration has been extensively studied, belongs to this family. Another globally-seen and migratory butterfly from this family is the Painted Lady. Raja, Prince, Nawab, Begum, Caliph, Emperor, Courtesan, Joker, Jester, Archduke, Duke, Duchess, Baron, Baronet, Earl, Viscount, Commander, Commodore, Pasha, Sergeant, Sailer, Constable, Map, Maplet, Popinjay, Brown, Crow, Tiger, Panther, Faun, Nymph, Oakleaf, Palmfly and Pansy are imaginatively named Nymphalids that you would enjoy observing. Many of them can be seen in forested regions, but several can be observed even in urban spaces. Food plants for caterpillars and adults of Nymphalids include common hedge plants, such as Oleanders, Lantana, Duranta; the most common wild plant, namely the Calotropis; and the cultivated flowering plants of family Compositae.

E) Family Hesperiidae: Their common name – 'Skippers' – describe their habitual quick darting flight. Small, stout and hairy, many butterflies of this group are often mistaken for moths, with which they are more closely related than other butterfly families. You can recognise Skippers by their hook-shaped or comma-shaped antennae that are distinctly different from the club-shaped antennae of most other butterflies. Many may be observed at dawn and dusk, although some can be spotted even during the day. Several of them are pests of cultivated plants such as bananas and rice. In fact, a large number of banana plants in southern India were destroyed in a recent outbreak of the Torus Banana Skipper *Erionota torus* (also called as Banana Leaf Roller or Palm Red Eye). Awls, Darts, Swifts, Flat, Angle, Ace, Skipper, Hopper, Flitter, Demon, Bob, Ace, Redeye, are some examples of the approximately 321 Skipper species found in India.


**Figure 12a.** Orange Oakleaf


**Figure 12b.** Common Evening Brown


**Figure 12c.** Green Commodore


**Figure 12d.** Popinjay


**Figure 13a.** Pale Green Awlet


**Figure 13b.** Common Red Eye


**Figure 13c.** Chestnut Angle

## Butterflies in the classroom

Butterflies are best studied by undertaking a field trip. Some of these studies can then be continued in the classroom.

### 1) Butterfly conservatory in the classroom

Observe butterflies inside the class: You can invite butterflies into your classroom if you are willing to put in some time and effort. This is not very difficult. You need to set up a few potted plants in your classroom. Students may enjoy setting up these plants and looking after them.

Visit the nearest nursery to get the necessary materials such as flower pots, soil manure and few plants saplings. Kalanchoes are succulents that don't need much looking-after once they are planted in a pot. All they need is sunlight, warmth and occasional watering. Kalanchoes are food plants for the commonly noticeable Red Pierrot. Since they are like Bryophyllum, you can use these plants to teach vegetative propagation also. While at the nursery, choose a *Nerium* plant and grow it in a large or at least medium sized pot. These too can stay in your classroom. *Nerium* will soon attract Tiger butterflies, especially the Glassy Blue Tiger or even the Plain Tiger. If you want more species, then consider growing *Tridax procumbens* and *Crotolaria sp*, both of which may be found growing in wastelands or by the road side. You could also grow *Aristolochia sp*., a beautiful plant with basket-like fruits, which is the favourite food plant of Swallowtails. If butterfly visitors don't arrive within a month, then you may have to take your students for a field trip to go caterpillar hunting.


**Figure 14.** Common food plants for butterfly caterpillars - a) *Crotolaria sp.*, b) *Calotropis* sp., c) *Nerium sp.*, and d) *Aristolochia sp.* e) *Tridax procumbens*

**2) In search of a caterpillar**

The best time to set up a butterfly conservatory is a couple of weeks before the monsoon. The search for caterpillars can take place anytime, but you are bound to see them during the monsoons. Look for caterpillars underneath leaves of plants. If your school has a garden, then you can search for caterpillars within the campus. If you are lucky, you might even chance on butterfly eggs. Try to get caterpillars that are generally found on Calotropis or Curry-leaf plants for they will not be fussy about changing their diet to *Nerium* sp.

**3) Rearing caterpillars to watch the emergence of butterflies (this activity is common in schools but I have made it quite integrated)**

I. This is in case you have chosen a caterpillar from a plant other than the ones I have mentioned before.

Materials needed: A well aerated box with a perforated cover to house the caterpillar. Make a small glove out of a clean plastic bag to handle the caterpillar. Some tissue paper to clean the box. A weighing scale. A tabulated sheet to record daily observations.

II. If you have collected caterpillars from the plants I have mentioned above or find that the caterpillars you have collected feed on *Nerium*/Oleander leaves, then the materials described before are not really necessary.

You can use this opportunity to teach a few math concepts. Record the weight of the caterpillar before you introduce it into the box/plant. Weigh leaves in the box to know how much a caterpillar eats/day. Since leaves may be very light, discuss with students how they can be weighed, especially without a sophisticated electronic balance (Hint: Add some heavy materials to the leaves to weigh. Subtracting the mass of the heavy materials will give you the mass of the leaves).

Make a record of as many features as you can of the caterpillar, including its length and colour. Observe how the caterpillar chomps away the leaves. As it eats, it also defecates. If you want, collect the droppings and weigh them. This will give you a rough idea of how much of leaf has been utilised by the caterpillar and how much has been egested. These are only rough calculations to give you a sense of food requirements.

Caterpillars will moult at least three to four times before pupation. Make a note of the same. Collect the moulted skin and carry out a few chemical tests – for example, you can take small bits of the moulted skin and perform tests of starch, sugar and proteins.

You can run similar tests with the droppings of the caterpillar. In fact, some droppings can be tested for the presence of chlorine, sulphur etc.

Keep track of the growth and any noticeable changes in the caterpillar. If you see it starting to eat less and becoming more sluggish, you can be certain that it is preparing for pupation. If the caterpillar is in a box, provide a small sturdy stick for it to pupate on. Keep observing the pupa for any noticeable changes.

Now wait for the emergence. If the species is a Tiger or a Crow, then the wait may not be for more than a week or two.

What can you teach through this activity?

Use data to revise concepts on measurements and units of mass.

Chemical analysis.

Metamorphosis.

Discuss the significance of the difference in foods consumed by the caterpillar and the adult to the survival of the species.

**4) In search of the butterfly**

While you are out looking for caterpillars, you may also try a few tricks to attract butterflies. Butterflies feed not only on the nectar from flowers, but also, as mentioned earlier, on carrion. If you leave a few dead fish, crabs or shrimps at a spot which is moderately sunny - you will soon find several Nymphalids arriving to feed on them.

**Figure 15.** Common Nawab feeding on a fish.

Observe the feeding butterflies from a distance. If you happen to be doing this near a wooded area or in a hilly region you will surely see the Raja, Earl, Nawab, Yeomen, and even some Papilionids visiting the meat. While observing them, shift your position so that you can see the light falling on their wings at different angles. You will see how the colours on the wings change their hues based on the light falling on them. Make notes and drawings, and once back in class, use the references quoted in this article to understand more about what you have observed.

**5) Observing scales under the microscope**

For this activity you will need a small piece of a dead butterfly's wing. If you can't find a dead one, you may use a net to trap a butterfly, and then, very gently, pass a soft paint brush over its wings. Don't try to catch the butterfly with your bare hands – you will harm its wings. Release the butterfly once you are done.

Dust the brush over a glass slide and add a drop of glycerine over it. Place a cover-slip over the glycerine. Use a filter paper and wipe away any excess of glycerine that flows from the edges of the cover-slip.

**Figure 16.** Scales of a butterfly wing under 10X magnification. Source: Dr. Thomas G. U.S. Fish and WildlifeService Headquarters, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Butterfly_scale_pattern_(6293105393).jpg. License: CC-BY.

Take a compound microscope and set it up with a 10X magnification. Place the slide you have just prepared on the platform and focus. Observe and you will see the scales of the butterfly.

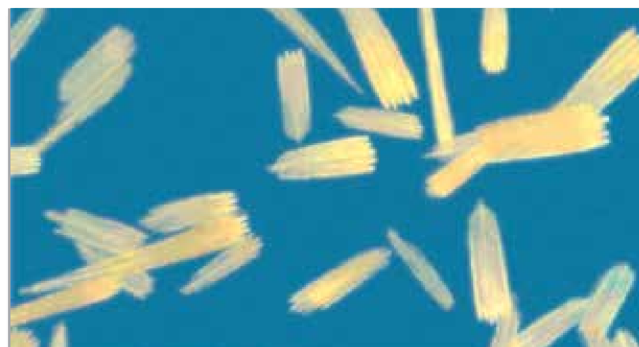

**Figure 17.** Individual scales when the 'dust' is focused under 40X or 60X magnification. Adapted from photo by Jan Homann, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Mottenfl%C3%BCgel_in_Mikroskop.jpg. License: Public Domain.

Observe the slide under higher magnification. Play with it by changing the amount of light falling on the specimen. At the end of the class, discuss the importance of scales on the wings both with respect to flight and colour. This will also be a good opportunity to discuss concepts related to wavelengths of light, colour, refraction and reflection.

In case you manage to find a piece of dead butterfly wing, investigate its colour by doing one of the following:

1. Carry out activity 5 with it instead of trying to catch a butterfly. Dust it on a glass slide to get some scales, and follow instructions given above.

2. Take it out in the sun and tilt it in any which way you want. Do you see any difference in colours? Do you observe iridescence?

## Scales and colour

What looks like dust on your fingers when you touch the wings of a butterfly are actually its scales. The arrangement of scales on butterfly wings is responsible for both their colour and patterns.

How? The colours that you see are the result of two different mechanisms - one resulting in 'normal' colour, and the other in 'iridescent' colour. 'Normal' colour is produced as a result of the simple process of absorption and reflection. Pigments present on the butterfly wings absorb some of the wavelengths of light and reflect others which we see as say yellow, green or red etc. 'Iridescent' colours are produced as a result of interference of light falling on the scales due to multiple reflections. The iridescent colour your eyes see on the wings depends on where you see the wings from. Since this iridescence depends on the arrangement of scales on the wings, these colours are also called 'structural' colours. Butterfly wing colour could also be produced as a combination of the two. If there is a pigment that can reflect yellow present on the iridescent surface, then the resulting colour could well be a 'normal' i.e., non-iridescent green

**Figure 18.** Indian Purple emperor showing change in shades of colour.

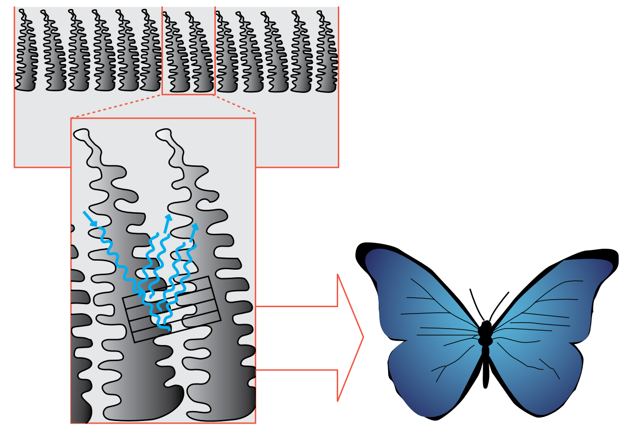

**Figure 19.** The nano-scale structure of butterfly wings. The tree-like structures are the arrangement of scales. The 'tree' and the air in between are the two materials with different refractive indices that facilitate constructive interference[12].

### Structural colours

Even in the absence of pigments, some brilliant colours can be produced simply as a result of optical effects such as refraction, diffraction or interference. Examples of these include the colours reflected off the shining surface of a CD or in a soap bubble. Since these colours depend on the way physical structures interact with light, they are called structural colours.

In butterfly wings it is the arrangement of scales that produces structural colour. While details of the arrangement of scales are beyond the scope of this article, in simple terms, these scales are arranged in a highly ordered fashion but in layers with air gaps between them. This arrangement allows for interference to operate. The light waves strike the scales in one layer and while some light waves get reflected, others continue to travel to the next layer and the following one, striking the scales of each layer to get further reflected. So light gets reflected numerous times. These light waves may not be in phase; the scales and the air gap between them are materials with different refractive indices; thus resulting in 'constructive interference' that strengthens the reflection. The collective effect is the iridescence. When the angle at which light strikes the wing changes, the constructive interference also changes – thus, resulting in different hues of a colour.

## Conclusion

Butterflies need not remain part of your science class only. They can also be part of a language or art lesson. Share this poem with the class as you finish the lesson on butterflies.

**WANT TO GET STARTED?**

**Check out our cool pocket-size butterfly pamphlet on the back-cover of this issue!**

# POEM

*Butterflies go fluttering by*
*On coloured wings that catch the eye.*
*On wings of orange, and silvery blue,*
*On wings of golden yellow, too.*
*Butterflies float in the air,*
*Making their homes most anywhere:*
*The rainforest, field, and prairie land,*
*On mountaintops, and desert sand.*
*If winter brings the cold and snow,*
*To warmer climates, off they go!*
*Returning home the following spring,*
*Beautiful butterflies on the wing!*

– Author Unknown

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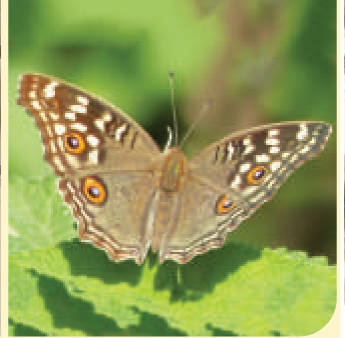
**Geetha Iyer** is an author and independent consultant working in the twin fields of Education and Environment. She has written extensively on topics in education, environment and Natural History. Geetha can be reached at brownfishowl@yahoo.co.uk

**GREAT EGGFLY MALE**
*Hypolimnas bolina*

**DANAID EGGFLY MALE**
*Hypolimnas misippus*

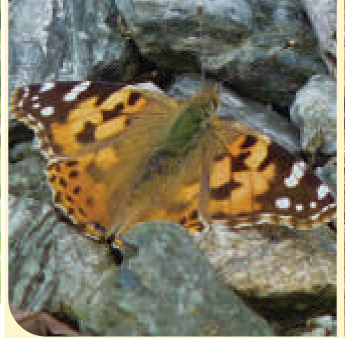
**CHOCOLATE PANSY**
*Junonia iphita*



**LEMON PANSY**
*Junonia lemonias*

**BLUE PANSY**
*Junonia orithya*

**YELLOW PANSY MALE & FEMALE**
*Junonia hierta*



**PAINTED LADY**
*Vanessa cardui*

**COMMON MAP**
*Cyrestis thyodamas*

**COMMON SPOTTED FLAT**
*Celaenorrhinus leucocera*

**COMMON BANDED DEMON**
*Notocrypta paralysos*

**COMMON FIVE-RING**
*Ypthima baldus madrasa*

**GLAD-EYE BUSHBROWN**
*Mycalesis patnia*

**COMMON EVENING BROWN**
*Melanitis leda*

**COMMON BARON**
*Euthalia aconthea garuda*

**COMMON SAILER**
*Neptis hylas*

**COMMON LEOPARD**
*Phalanta phalantha*

**COMMON JESTER**
*Symbrenthia lilaea*

**COMMON LASCAR**
*Pantoporia hordonia*

**COMMON CASTOR**
*Ariadne merione*

**INDIAN SKIPPER**
*Spialia galba*

Azim Premji University

# Pollinators or plant munchers? - Butterflies

*Geetha Iyer*

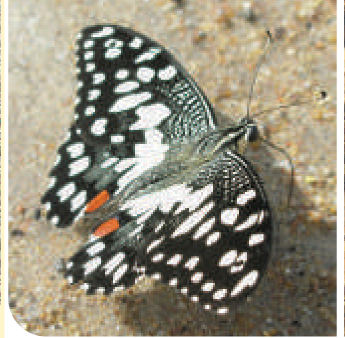
i wonder...
Rediscovering school science

**'What's that butterfly', don't we often wonder?** This pamphlet identifies some butterflies you are likely to see across different parts of India. You can read more about each of them in the article on butterflies in the June 2016 issue of *I wonder*.

The first seven images are of papilionids or swallowtails, followed in turn by four pierids or whites and yellows, and five lycaenids or blues. Appearing next are many nymphalids or the brush-footed butterflies, with the last three being the hesperids or skippers.

**MALABAR RAVEN**
*Papilio dravidarum*

**PARIS PEACOCK**
*Papilio paris*



**COMMON LIME**
*Papilio demoleus*

**YELLOW ORANGE-TIP**
*Ixias pyrene*

**COMMON GULL**
*Cepora nerissa*

**LONG-BANDED SILVERLINE**
*Spindasis lohita*

**FORGET-ME-NOT**
*Catochrysops strabo*

**PLAIN TIGER**
*Danaus chrysippus*

**STRIPED TIGER**
*Danaus genutia*

**GLASSY TIGER**
*Parantica aglea*

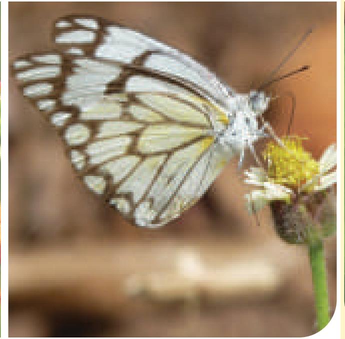
**CRIMSON ROSE**
*Pachliopta hector*

**COMMON ROSE**
*Pachliopta aristolochiae*

**COMMON MORMON**
*Papilio polytes*

**COMMON BLUEBOTTLE**
*Graphium sarpedon*

**INDIAN JEZEBEL**
*Delias eucharis*



**PIONEER**
*Belenois aurota*

**FLUFFY TIT**
*Zeltus amasa*

**COMMON PIERROT**
*Castalius rosimon*

**PUNCHINELLO**
*Zemeros flegyas*

**TAWNY COSTER**
*Acraea terpsicore*

**BLUE TIGER**
*Tirumala limniace*

**COMMON CROW**
*Euploea core*

# NATURE CALLS

## A series of nature-based outdoor activities

NATURE CONSERVATION FOUNDATION (NCF)

Did you know that the outdoors, teeming with plants, animals, birds and insects can transform into an immersive and captivating classroom? Nature Calls is a series of nature-based activities designed to encourage students to explore their surroundings, and stimulate their wonder and curiosity about nature.

Students, especially in urban areas, do not get to spend much time outdoors and in nature. But, a small park, an empty or abandoned plot of land or garden in school or at home, even in a crowded city or town can transform into a nature hotspot! For example the bark of trees, leaf litter and shrubs are home to ants, mantids and spiders. Concrete walls and small water puddles can house moths, bees, wasps, dragonflies and even frogs!

We present a series of nature/outdoors activities designed to encourage children to observe and experience the natural world. These activities feature a range of plants and animals that students are most likely to come across in and around their homes, gardens, parks, school campuses and playgrounds.

The design of these activities is deliberately kept simple. In a world filled with technology and other distractions, where learning typically happens in a closed-room environment, our aim is to encourage children to slow down, observe the abundance and diversity of life that surrounds them, and help uncover the sense of discovery and wonder that the natural world offers.

### Tips to Teachers

- Share the theme of every activity with your students a few days before you actually do it. On the day of the activity, encourage students to share their understanding, ideas and questions about the theme before you start.
- Emphasise that observing nature does not mean that they must try to identify or name every animal, plant, bird or insect that they come across. Instead, the purpose of these activities is to see how well they can describe in their own way what they observe, and using a medium (written, sketches, poems, pictures) they are most comfortable with. Encourage them to describe an animal or plant that catches their interest in as much detail as possible. With the first such species that you observe together, ask them questions like, what is the insect doing? Can you describe the place we are seeing it in? Do you remember seeing this insect elsewhere? Can you see the insect interacting with any other forms of life? What according to you is unique about this insect? Do you know of a name for it in any language?
- Encourage your students to keep a nature journal. This can even consist of a few sheets of one-sided paper stapled together. Let each student decide how she wants to record her observations – as descriptions, poems, sketches, or even collages made of pressed plant parts that she finds interesting. Open-ended questions like, “If I were a

dragonfly…" or "If I were a ficus tree…", might help steer students to make a start.

- All activities can be done individually or in small groups. Encourage students to share and discuss their observations with each other at the end of every activity.

## Conclusion

We hope you and your students enjoy these activities. We also look forward to hearing about your experiences in doing them as well as any suggestions on making them more engaging to students.


## Acknowledgements

Activities featured here are part of a more extensive compilation called Nature Calls. Designed as nature/outdoor activities for children from the age of 8 to 14, this is an educational resource developed by the Nature Conservation Foundation, and supported by Wipro Applying Thought in Schools, Bangalore. Nature Calls is freely available online (www.edu.ncf-india.org), with each activity provided in the form of a high-resolution PDF file that teachers can print and use in their classrooms. The online resource also has additional information listed under each activity, a contest encouraging children to send their observations, and space for any questions that teachers or students may have about the activities/topics covered in them. Teachers (especially from areas with poor or unreliable internet connectivity) who would like to receive a printed copy of these activities are requested to write to us at Nature Conservation Foundation (edu@ncf-india.org).

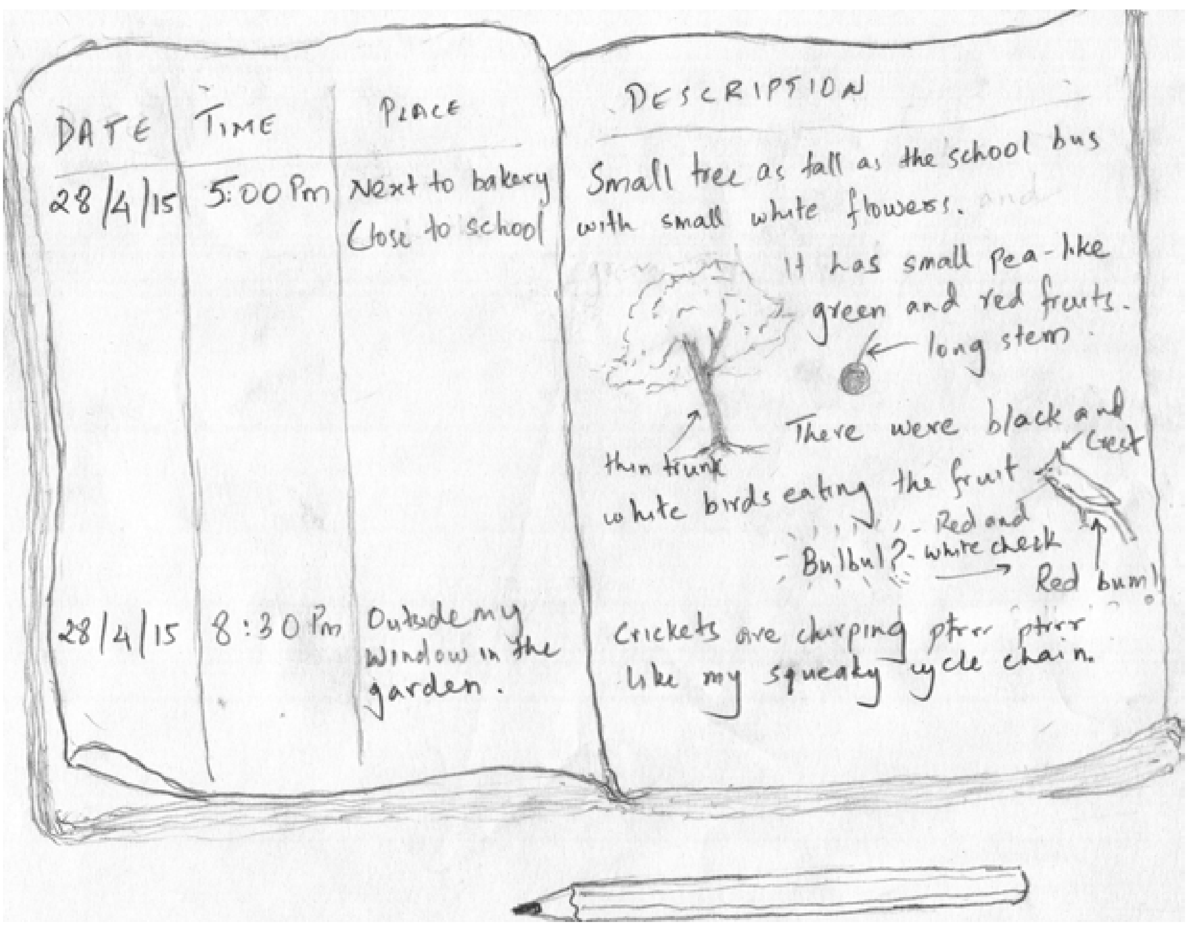




**Figure 1.** An example of a field diary. Source: Content and Research - Nature Conservation Foundation; Design and Layout - Brainwave Magazine. URL: www.ncf-india.org and http://www.edu.ncf-india.org/.

**Nature Conservation Foundation** (NCF) is a non-profit organisation focussing on research and conservation of the natural world. NCF's Education and Public Engagement Programme runs several projects to engage with children and adults in ecological observation. NCF also develops, displays, and distributes nature education material. For any queries, please contact edu@ncf-india.org

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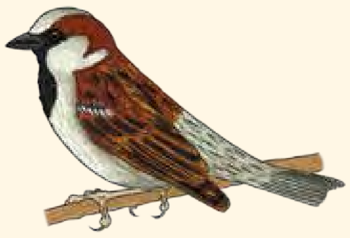
# Chirp Chirp

## An Old Friend

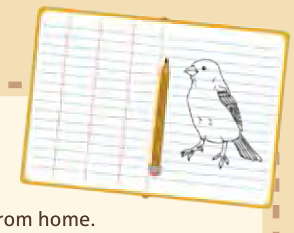
House sparrows have been hopping in and around our homes for centuries; nesting in street lights, under roof tiles and on ceiling fans, looking for food in our kitchens, our backyards, by the roads and in our fields.

When they are not building nests and taking care of young ones, house sparrows live in groups. They are noisy birds and talk to each other using a variety of calls. They cheep, chirrup and chatter. They also let out shrill calls when they detect danger or when in distress.



Male and female sparrows are of different colour patterns. The males have a grey head (crown), black bib, white cheeks and are a dark brown with streaks of black on their back.

Females are a paler brown all over without the grey crown, black bib and white cheeks.



## For the Field Diary

**Get outside** Note the time in your diary when you set out from home.

**Spot them** If you see one or more sparrows, note where you found them - out on the road, in a garden, on a compound wall, feeding at a garbage pile - where did you see them first?

**Count them** How many in the group? If you find a group of house sparrows, watch them for a while. How many males and females do you see? Can you the see black bibs on the males?

**Other details** It's important to also note the location, date, start time and end time of your walk, and the rough distance you covered.

Alert, with its head up

Feeding

Two males being aggressive

## What if I can't find any?

If you can't find sparrows, only other birds, this too is important information. Sparrows are on the decline in many places and it's good to know not just where they are seen, but also where they are not. This decline may be for a variety of reasons - fewer nesting places, less grain for the adults and fewer insects for the chicks than there used to be.

## Contest

According to a superstition, a sparrow flying into your home denotes good luck (especially if it then builds a nest in your home). Ask an elder in your family if they know of any such beliefs about sparrows.

Visit us at www.edu.ncf-india.org and share you notes from your field diary, and read what others saw when they went sparrow-spotting. Also find out about other popular sparrow stories and share one with us at at edu@ncf-india.in for a chance to win a field guide to identify birds.

You can also write to letters@planetbrainwave.com if you have other feedback.

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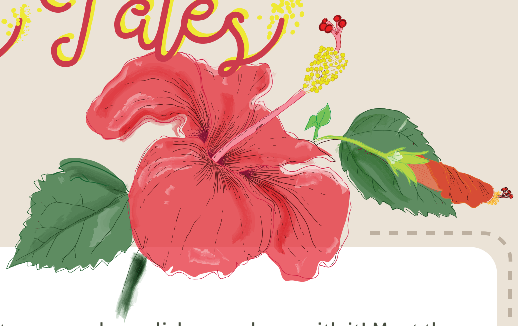
# Hibiscus Tales



## Flower for a Day

You can not only eat this flower but you can also polish your shoes with it! Meet the 'shoe' flower or the hibiscis. Once open, the hibiscus adorns your surroundings for just a day. As the sun sets, it falls off the plant and dies.

There are over 200 species of hibiscus. The one with big flowers that we commonly see in gardens is called the Chinese Rose.

## A Refreshing Cup of Hibiscus Tea

Thousands of years ago, the Pharaohs of Egypt used to drink hibiscus tea. Even today, it's a common drin in Egyptian weddings. Find out how hibiscus tea tastes for yourself. It's quite easy.

- Collect some freshly-fallen flowers of the hibiscus plant you've located. Make sure no pesticide has been sprayed on them. Remove the green sepals at the base, the central yellow bulbs, the velvety pads and their stalks.
- Wash them well and to 1 cup of flowers pour 4-5 cups of boiling water. Cover the mix and let the flowers soak for 4-5 minutes. Hibiscus flowers also work as a dye, so make sure they don't stain your clothes.
- Strain the juice through a fine sieve, stir in some sugar (to your taste). Some people like to add lemon wedges, mint or orange zest to add to the flavor of the tea.
- You can also dry the flowers well in the sun and store them to use later on.

## For the Field Diary

Locate a flowering hibiscus plant (maybe there's one in your garden or somewhere in your neighbourhood). Take a measuring tape and a magnifying glass, and visit the plant at sunrise. If you arrive early enough, you can actually see a flower blooming right in front of your eyes as the sun starts to rise.

- How tall is your hibiscus plant?
- Look at several leaves. What shapes are they? Looking at the leaves, draw them in your diary.
- How many flowers are there? What do they smell like?
- Do you see a long, thick noodle sticking out of the flower? It has little yellow bulbs on the side and little velvety pads at the end. The yellow bulbs have pollen. Use your magnifying glass to see if you can spot any pollen on the red pads.
- Note the length of the tube made by the petals. At the bottom of this tube is where you find the flower's nectar. How long would an insect's tongue or the beak of a bird have to be to reach the nectar? Use your measuring tape to find out and note the length in your diary. What if a bird or an insect can't reach down the tube – is there some other way of getting to the sweet syrup?

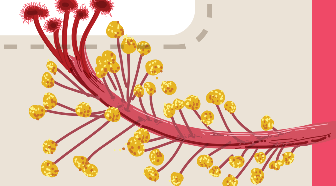
Look for fruits. The thing is, you may not find one. Many people, even botanists haven't seen the fruit of a hibiscus. Is it possible that a plant has flowers but the flowers don't make fruits?

*Send us your drawings and notes from your field diary.*
*If you saw any insects or birds at the hibiscus plant, let us know.*

## Contest

Ask an elderly relative what the hibiscus is called in your mother tongue and the different ways they used the flower. Ask your friends and neighbours what it is called in their language.

Send us your list of names (the longer the list, the better) or your drawings and notes from your field diary at *edu@ncf-india.org* for a chance to win a book on Indian plants.



Visit NCF at *www.edu.ncf-india.org*
You can also send in feedback to *letters@planetbrainwave.com*

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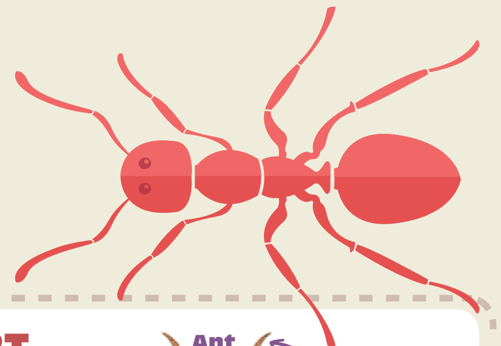
# ALL ABOUT ANTS



## MEET THE EXPERT

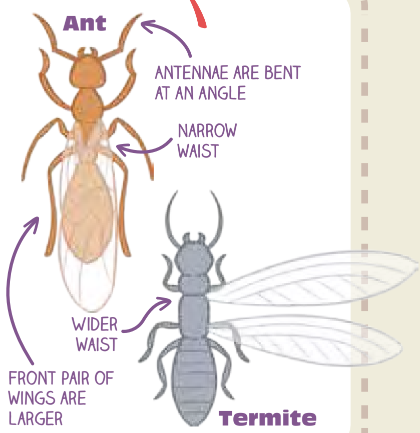
Meet Joyshree, the myrmecologist who is mad about ants.

### ? Why ants?

**Joyshree:** Well, many reasons! For one, ants are truly social animals just like humans. They live in well-organised colonies. Also, there are so many trillions of ants that their weight would account for about 15-20% of the total weight of all animals on land!

### ? How do I know if I'm looking at an ant or a termite?

**Joyshree:** Good question. Most of us mistake termites for ants. The differences are illustrated on the right.




## Spy on an Ant family

**What you need:**
Some sugar, a bit of cardboard, a couple of stones and your field diary.

**STEP 1:**
Find an ant, follow it and locate its colony/nest.

**STEP 2:**
A metre or so away from the nest (if you don't find a nest, an ant trail will do), where you see ants wandering about, place the cardboard, weigh it down with the stones and put the sugar on it.

**STEP 3:**
Note down the following in your field diary:

a. How soon after you place the sugar do the ants find it?
b. Record the number of ants on the site every 2 minutes, for 10 minutes.
c. Do the same with different kinds of food like salt, lemon, green vegetables, a bit of a boiled egg, maybe even a dead insect. If you find a different kind of ant, compare their preferences.

## HOW ANTS LIVE


Artwork: Pooja Prabhakaran

## CONTEST:

Log in to **www.edu.ncf-india.org** or email us at **edu@ncf-india.org** (Subject: Ants). Tell us how the ants reacted to the various foods you presented them with for a chance to win a book on insects. You can also write to **letters@planetbrainwave.com** with other feedback.

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# Bark Bites

## Eating Bark

Beetles, termites, elephants, deer, porcupines and even humans eat bark!

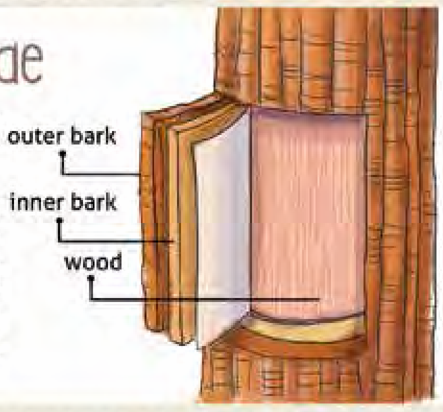
All you need to be a good bark eater is sharp mouth-parts to cut into the wood, and digestive systems to break down the tough wood. Humans can't do the latter very well. In fact, some kinds of bark are toxic for us.

However, if you've eaten cinnamon, you too have eaten bark. Can you think of any other kind of bark that is edible?

## Sweet and sappy inside

Bark doesn't look like it would taste very good, does it? In fact, it looks like it would taste rather... woody.

This is largely true of outer bark – which is mostly dead. The inner bark (also called the phloem) has some living cells as well as a watery sap – sugars and other plant food dissolved in lots of water. This sap is transported to different parts of the plant. Excess food is also sometimes stored in the inner bark. It's this inner bark that is edible.




## Protective Bark

Tree bark is a layer that stands between the elements outside and the inner wood of a tree. Some bark are water-resistant and can provide excellent insulation. In some trees when the bark is punctured, a resin flows out and hardens. In the activity above, you may have noticed resin on the trunks of some trees.

## For the Field Diary

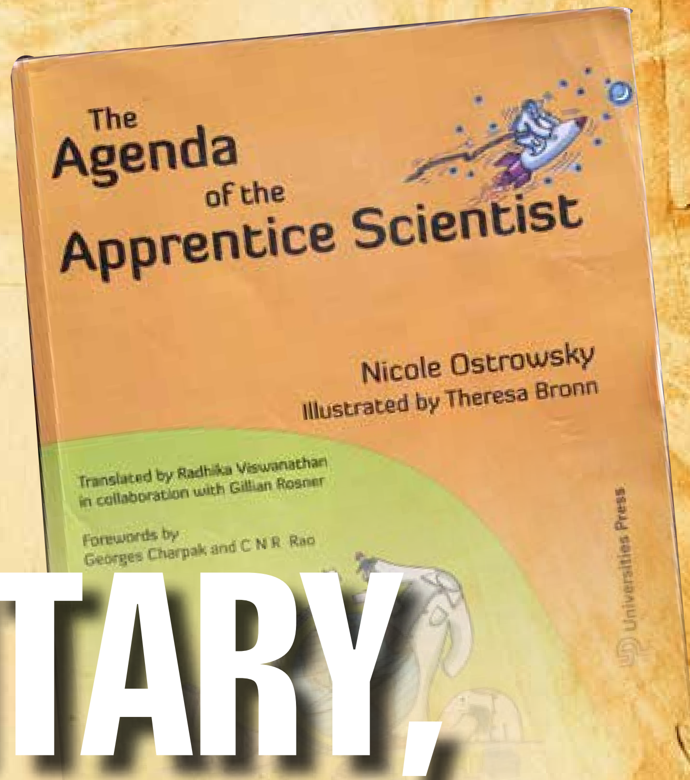
The colour and texture of its bark can help you identify the tree. For example, the eucalyptus has smooth, thin bark that it often sheds, and mango bark is rough to touch but you can peel it off in thick slabs. Let's go explore tree bark. Do this on a non-rainy day.

- Find trees in your garden, by the roadside or in your neighbourhood park that have different kinds of bark – smooth, flaky/peeling, rough, pitted, fissured, crocodile skin-like. Find at least five different kinds.
- Examine each bark. What does it look like? What colour is it? What does it smell like? What is its texture like? Do you see any sticky or hard blobs (resin) on it?
- Peer closely at the tree trunk and list all the insects and other life forms you see on the tree trunks scurrying about or nestled in the fissures and cracks. Did you see any fungus on the tree trunk?
- Place a sheet of plain paper firmly against the bark of a tree. Using a pencil, piece of charcoal or crayon, gently rub over the bark. Use different colours, if you'd like. Make at least one bark rubbing for each tree.
- Compare the bark rubbings you have made and the notes on the bark of each kind of tree – do different trees have distinctly different kinds of bark?
- Did you find any insects or fungus on the barks you observed? Which of your trees housed the most life forms? On which trees did you find more creatures?

## Contest

Send us your bark rubbings. Write to us at *edu@ncf-india.org* and tell us about the different kinds of bark you observed, and all the living things you managed to spot on them for chance to win a book on Indian trees.

Visit NCF at *www.edu.ncf-india.org*
You can also send in feedback to *letters@planetbrainwave.com*




# ELEMENTARY, MY DEAR WATSON!

ISHAAN & SANGEETHA RAJ

Are you looking for a book that offers a fun, new perspective to science? In this review, join a mother and son as they share their experiences of one such book, called The Agenda of the Apprentice Scientist.

Written by Nicole Ostrowsky and illustrated by Theresa Bronn, **The Agenda of the Apprentice Scientist** is a book that is 'accessible to everyone, from 7 to 107'. It explores concepts that make sense to even students at the upper primary and middle school levels (9–13 years) through experiments that can be done at home with easily available materials. By inspiring one to be curious and playful in the exploration of science, it can be appealing to anybody, even those who consider themselves to be far removed from the world of science!

The author has worked as a research scientist for decades, and is now Professor Emeritus at the Laboratory of Physics and Condensed matter at the University of Nice, France. The original edition, written in French, has been translated into English by Radhika Viswanathan and Gillian Rosner. Published in association with the French Embassy in India by Universities Press, the book is available for Rs.553 on Flipkart and Amazon (India).

If you are looking to buy a copy of this book, please send an email to the distributors at:

info@universitiespress.in

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Delivery anywhere in India. Discounts available.

For Kannada copies - please contact Prabhakara Reddy.

**Ishaan:** I first saw **The Agenda of the Apprentice Scientist**, when Yasmin aunty (the chemistry teacher at CFL, and my mother's friend) lent it to me. After looking through the book and doing a few experiments, I decided to get my own copy.

Unlike many books that say 'Experiments to do at home', **The Agenda of the Apprentice Scientist** sticks to its word. It asks only for materials such as paper, straws, balloons and ice cubes. This makes doing the experiments much easier. I recently came across a book that required two gallons of liquid nitrogen to freeze homemade ice cream!

**The Agenda of the Apprentice Scientist** gives you an experiment, a quote on the experiment, an explanation, and last but not least, a hilarious illustration of apprentice lab coats on every page. At the top of every page is the title of the activity followed by the instructions. Since this book wants to give the reader an experiment to do every day of the year, instead of a page number there is a date, such as March 3rd or June 10th. In the middle of the page there is a large white space for the reader to note down observations. There is also a quote about the activity. The quotes vary from funny to philosophical to inspirational. August 22nd and 23rd are both activities that involve freezing but the quotes are so different. On 22nd, it says "True friendship doesn't freeze in winter" and on 23rd, "He who got burnt with hot milk will blow on his ice-cream to cool it down". Towards the bottom of the page is an illustration of the apprentice lab-coats doing the experiment and comparing results, and making funny remarks.

One of the reasons I like this book is the way concepts are explained. They not only tell the reader what happens when you put baking powder in vinegar (Mar 8th) - the vinegar starts bubbling and the balloon slowly inflates, but also how and why, what happens, happens (one of the ingredients of the baking powder reacts with the vinegar to create carbon dioxide. This fills the bottle and inflates the balloon).

The book has experiments that people of all ages can enjoy and learn from. Many of the activities are very simple but the results can be very exciting, such as making smoke rings (Nov 24) using a cardboard tube or making different types of paper airplanes (May 25). On many occasions I have got adults and children alike to participate enthusiastically in these experiments.

> "Unlike many books that say 'Experiments to do at home', The Agenda of the Apprentice Scientist sticks to its word. It asks only for materials such as paper, straws, balloons and ice cubes."

Most science books are written on one subject such as Chemistry, Biology, or Physics. Although sticking to the fundamentals, this book covers all three. The book is not divided into thematic sections, but some topics (such as temperature, sound etc.) are clubbed together. When using the book one can follow the 365 activities (one for every day of the year) in order, or do them at random. Certain activities continue over more than a day/page - it is necessary to do these in the right order.

There is only one thing that I found confusing in this book — the Index. When I searched for an experiment in the Index, such as the Smoke rings experiment I mentioned earlier, I looked for keywords such as smoke or rings, only to find the experiment under incense. When I looked for the vinegar and baking soda experiment, I found it under balloon. Another instance was when I wanted to show my friend the famous wineglass experiment — where, by slowly moving your finger along the rim of a wine glass which has been smeared with a thin layer of vinegar, you make the glass sing (June 6th). I looked under W for wineglass and under V for vinegar but finally found it under P for pitch. I think a Contents page with the title of the experiment might have been useful.

In conclusion I'd like to say that **The Agenda of the Apprentice Scientist** is one of the best books I've used. Each and every activity is worth trying.

**Sangeetha:** I opened the book tentatively, as I do all books related to science, and read the Foreword to the French edition. I felt a little bolder and ventured to read the Foreword for the Indian edition. Positively emboldened, I felt the apprehension fading and a mild curiosity began to occupy its place.

But as I turned to day one, that is, January 1st, I was rudely hurled back into my 8th standard classroom, sitting absently in the back row, doing my very best to go unnoticed by the science teacher. The illustration on page one has a lab coat, drawing a snowflake and saying "I am a scientist, not an artist". Oh! Another book, I thought, that simply defines and categorises the world, in order to make sense of it. I closed the book and forgot about it.

But the book appeared again and again, sitting at our dining table or reclining on our sofa, raiding our kitchen for eggs, salt, vinegar, match sticks, ice cubes, and so on, raiding my barely alive potted plants for earthworms, pulling open shelves for candles, twine, bits of copper wire. The book is not responsible for all of the raiding Ishaan did, although he was definitely inspired by it.

And those incomprehensible words, the ones I'd gladly erased from memory - inertia, diffusion, density, gravity, electrons, friction, and so on, began to feature regularly at mealtime conversations, and on long drives in the car.

My curiosity reappeared and I found myself participating enthusiastically in the discussions, and waiting a little anxiously for the outcome of this or that experiment.

To be able to tell the difference between a raw and boiled egg seemed like a useful skill to have, and it greatly amused me to see the boiled one spinning and the raw one toppling over. And then to learn that the liquid inside the raw egg couldn't just up and move at the same speed as the shell, gave clearer properties to the words 'solid' and 'liquid'. All I remembered about liquids from my school textbooks is that it takes the shape of its container.


**Figure 1.** A page from the book. Photo credits: Ishaan and Sangeetha Raj.

I took it to be primarily a book of science experiments; it proved to be more than that. The book took science out of that lofty lab, where I had placed it, and made it a part of everyday experience - accessible and commonplace. Not something I needed to study and 'get through', but something that I could engage with and enjoy, just as I did a good story or a poem.

**Ishaan** is a 12-year-old boy who has a keen interest in science, and is schooled at home.

**Sangeetha** volunteers at the Annaswamy Mudaliar School, where she teaches English. She is Ishaan's mother.

# OLIVER SACKS

## THE DOC ON THE BIKE AND IN THE BRAIN

THEJASWI SHIVANAND

Oliver Sacks was a neurologist who brought the brain to popular imagination in latter part of the 20th century. In the article, the author presents Sacks's work on brain phenomena, ranging from hallucinations and colour blindness, against the backdrop of his life that was as interesting as the brains and people he studied. Also highlighted is Sacks's remarkable ability to connect with and communicate about his 'patients' in a very humane way.

Imagine a doctor, a friendly gentleman with a white beard, who smiles genially at you from across his chair. He would like to know how you feel after being struck by lightning. You tell him how you have been suffering from blinding headaches since the incident - headaches that seem to resist medical intervention. A friend had suggested that you meet this doctor, a neurologist. Sitting at his desk, you add that you've suddenly discovered an irresistible taste for learning classical music, something you never particularly liked until you were hit by lightning. This doctor listens deeply, and seems to take furious notes on everything you say. He is interested in your headache, but seems to be more interested in your new found musical tastes. You discuss Bach and Debussy. At the end of the session, he writes out a prescription for your headache but asks you to visit him again. You thank him and leave his office. In a few months, you receive a handwritten letter from the doctor asking for your permission to include your story in a collection of medical cases that the doctor is compiling on people with interesting life stories around brains and music. You are thrilled to hear this, but would like anonymity in the book. He agrees. A year later, you walk by a bookstore and notice a new book on the shelves – Musicophilia by Oliver Sacks, your doctor, with your story featured prominently in it, without mentioning your name.

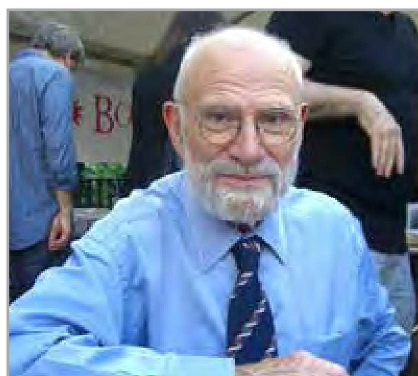

**Figure 1.** Oliver Sacks at the Brooklyn Book Festival in 2009. Source: Luigi Novi, Wikimedia Commons. License: CC-BY. URL: https://en.wikipedia.org/wiki/Oliver_Sacks#/media/File: 9.13.09OliverSacksBy LuigiNovi.jpg

The fictionalized description above is an attempt to capture the spirit and approach of Oliver Sacks, one of the greatest 20th century chroniclers and communicators of neurological stories. He could very well have been your doctor if you had lived in New York in the last three decades of the 20th century, and had a puzzling neurological condition. Dr. Sacks was a neurologist - a medical doctor who specializes in understanding the workings of the brain, especially under conditions where it malfunctions or displays unusual functions. The human brain looks like a lump of grey tissue, but has made our species capable of communicating in thousands of languages; create cultures, cities and the stock market. It can also be the site of life-changing conditions like depression, schizophrenia or dementia. The brain was Dr. Sacks' laboratory, and writing about the brain was his passion.

The brain is a complex organ. Some simple classroom activities like those described here: http://faculty.washington.edu/chudler/chmodel.html can be used to make the structure and function of this organ more accessible. This is another useful site: https://ntp.neuroscience.wisc.edu/teacher-resources.htm, with a wide-ranging collection of activities on introducing neuroscience to children of various age groups. Children may also enjoy seeing a brain preserved in formalin, possibly on a visit to a local hospital museum.

Dr. Sacks was an inveterate collector of stories, of people's lives and their brains. The fictionalised story here is similar to the hundreds of real-life stories that Dr. Sacks has captured in his 14 books[1] published over 45 years. In these stories, he has pondered over the marvels of the brain - from its ability to produce blinding headaches captured in his first book **Migraine**; its capacity for producing visions of objects that don't exist that he wrote about in **Hallucinations**; and the fantastic and universal ability of the human brain to create, process and appreciate music that he explored in **Musicophilia**. Instead of simply listing diagnostic criteria for various conditions he came across as a doctor, he recounted the life stories and case histories of the people he met during his years as a clinician.

**Figure 2.** Illustrated representation of a migraine aura.

Dr. Sacks was clearly moved by the people he met and wrote about in his books. In a case published as 'The Twins'[2], he describes the mathematical gifts possessed by a pair of twins he observed for some time in the 1960s and 70s. These twins possessed, among various other abilities, an intuitive ability to count prime numbers. He verified their ability by cross-checking the large multi-digit numbers they spoke aloud against a table of prime numbers. In a moving passage, he describes the close emotional connection they shared that became particularly evident when they played a game of exchanging ten digit prime numbers. He later describes the loss of this ability once the twins were separated and put on a programme to help them integrate into society. He leaves it to the reader to wonder about society's approach to such people – was separating the twins the right thing to do, given that they derived great joy in communicating to each other through numbers? His writing conveys the empathy he feels for their lives, something that you don't often expect to see in a doctor's typical report of a case. Sacks wrote about these people not as mere medical marvels or clinical objects for diagnosis, categorization and treatment; but as real people with real life stories, with their ups and downs, joys and sadness, connections and mishaps, as illustrated in the story of the mathematically gifted twins described earlier.

The story of the twins can be shared with children familiar with prime numbers. Children can be asked to come up with progressively larger prime numbers. First let them attempt these themselves, with any approach that they can think of on their own, like by dividing numbers. Then, introduce them to the 'Sieve of Eratosthenes' technique (http://www.geeksforgeeks.org/sieve-of-eratosthenes/), and ask them to identify the largest possible prime by this technique. Encourage them to time themselves. Compare this with the time taken by the twins, in Sack's case study, to identify very large primes intuitively.

Dr. Sacks' fascination for the brain may have begun at home. He was the third of four sons born to doctor parents in London on 9$^{th}$ July 1933. When he was seven years old, he survived the Blitz, the bombing of London by the German air force. He describes these early years in his memoir **Uncle Tungsten**[3] where he expands on what turned out to be a life-long fascination with chemical elements and the periodic table. This book is very instructive in appreciating the role of free exploration and questioning in a child's attempt to understand the world. He was too young to fight in the war, and so after it ended, he attended Oxford University in the early 1950s where he initially chose to qualify as an obstetrician. He shifted to neurology under the influence of two gifted teachers. He mentions them in his autobiography, **On The Move: A Life**, remembering them both with 'affection and gratitude' - one of them he credits for having taught him to be observant and intuitive; and the other, to look for possible physiological mechanisms underlying a particular set of behaviours[4].

**Figure 3.** The Human Brain. Source: wonderingpilgrim. URL: https://wonderingpilgrim.files.wordpress.com/2015/01/brain1.jpg

Introduce children to optical illusions by sharing some examples of such illusions.

Here are two good sources for illusions:

1. http://www.optics4kids.org/home/content/illusions/
2. http://www.michaelbach.de/ot/

Encourage children to come up with a theory that explains why we fall for these illusions. Ask them to test if the illusion persists when they look at it with one of their eyes closed. This can be tried out for one of the images in the links above. Ask children to repeat this experiment, with their other eye closed instead. What can you conclude? Does this hold for other illusions? How are illusions different from hallucinations? Encourage children to offer explanations, or come up with their own ideas for conducting this investigation; with teachers ensuring that care be taken before any experiments are actually attempted.

Dr. Sacks' books repeatedly reveal his intuitive approach to understanding underlying causes of neurological conditions. Nowhere is this highlighted more than in his **Awakenings**[5], where he describes his use of the drug L-Dopa to wake a series of patients who had been in a coma-like state for over forty years from their sleep. He also describes their reactions to the world around them in this awakened state, and their varied behavioural responses to the drug. This book, published in 1973, was later made into a movie that made him well-known in the United States where he lived since 1961. His primary work as a clinician was to diagnose and think of a course of treatment best suited to a particular condition. He seemed to have found validity in the use of medication, as he describes in the case of his younger brother Michael. Michael was diagnosed with schizophrenia as a teenager, and subsequently struggled with meeting the demands of society. Dr. Sacks describes his own struggle with trying to understand his brother's condition, and his sense of failure at not being able to personally help; but recognizes the role of medication in reducing some of the more debilitating psychoses and hallucinations[6].

He approached the case of Ray, who had Tourette's syndrome, with the use of medication. People with Tourette's syndrome display sudden, repetitive, non-rhythmic physical movements (motor tics) and utterances (phonic tics). Ray, whose condition is described in 'Witty Ticcy Ray'[7], was excessively impulsive, and showed 'tics, jerks, mannerisms, grimaces, noises, curses, involuntary imitations and compulsions of all sorts'[7]. Medication seemed to take away his symptoms, but it also took away his spontaneity and changed his personality completely. In such a situation, Dr. Sacks often wondered who the real Ray was. Through his detailed and humane medical descriptions, Dr. Sack's writing showed remarkable depth in connecting modern science and medicine with questions of social significance.

In his early days in the United States, in addition to meeting patients and practising as a clinician, Dr. Sacks explored the countryside on long bike rides[8]. Given his passion for speedy bike rides and adventures in the countryside (resulting in the occasional accident), people were often surprised to know that he was a doctor. He describes a walk in Norway in his 1984 book, **A Leg To Stand On**[9], where chased by a huge bull, he had a devastating fall from a cliff that left him with a badly broken leg. He goes on to describe how during his recovery, he sometimes strongly experienced the feeling of his leg as not being part of his body, a condition known technically as Body Integrity Identity Disorder (where parts of the body may feel like they shouldn't be there, demonstrating the intimate relationship between mind and body)[9]. Among his other talents, Oliver Sacks was a champion weight lifter[10]. He had to give this up

**Figure 4.** Doctor on a Bike.

The phantom limb phenomenon1[1] is a disorder where a person experiences the presence of a limb when it is actually not there, and can be looked symptomatically as the opposite of the Body Integrity Identity Disorder. The phantom limb phenomenon can be used to demonstrate the mind-body relationship and the idea that various parts of the body are actually mapped in different parts of the brain. This phenomenon can be easily demonstrated in class through the experiment described here: http://brainu.org/phantom-limb

as he grew older and his body began to feel the strain from his numerous accidents with bikes and bulls!

Dr. Sacks was very widely read. The extensive footnotes to his books reveal his eclectic taste - ranging from philosophy to poetry, although he was most fascinated by plants and natural history. He never travelled anywhere without his notebook and pencil, and was always ready to note anything he found interesting. In his **Island of the Colour-blind and Cycad Island**[12], he describes two strange stories about people living on these islands. The first story describes the high prevalence of achromatopsia (or complete colour blindness) that was common among the inhabitants of the Pingelap islands in the Pacific Ocean. Nearly 5% of the population of 3000 people on this island suffered from this disorder, i.e., they see their world in black, white and shades of grey. In comparison, only 1 in every 30,000 people across the world is affected by the same condition. Dr. Sacks connects the occurrence of a typhoon in 1775 and the genetics of island populations with these high rates of prevalence.

To introduce Red Green Colour blindness in class, use the Ishihara Colour blindness Cards, available online at: http://colorvisiontesting.com/ishihara.htm. This activity can be used to understand how the eye detects colour. When introduced along with physical models of the brain, these cards can also be used to understand visual processing in the brain.

The second strange story was of the people living on Guam, a remote island in the Pacific Ocean. These islanders experienced symptoms of dementia, typically a disease of old age, where people slowly lose their normal bodily functions and memory due to the death of their brain cells (neurones). The rates of dementia on this island were a hundred times higher than in any other part of the world. Detailed medical investigations showed that the brains of people who died from this disease revealed a high concentration of a particular chemical.  Further investigations revealed that this chemical was probably derived from fruit bats that were consumed by the islanders. Bats possessed high concentrations of the chemical because they fed on the fruit of cycads, a tree species that grew commonly in Guam, which had high concentrations of this chemical. With over-hunting leading to a decline in fruit-bat numbers, the disease disappeared from the island as well. The story of this (Lytico-bodig) disease is another in Dr. Sacks' long list of descriptions and observations that have been so useful in asking good questions in science. After all, science builds on such detailed observations, and it is questions and theories that stem from these observations and experiments that help test and reject unworthy ideas. Dr. Sacks' observations and experiments, such as those described in **Awakenings**, are of the kind that stimulate questions which can be investigated experimentally to understand the underlying basis for the brain's function.

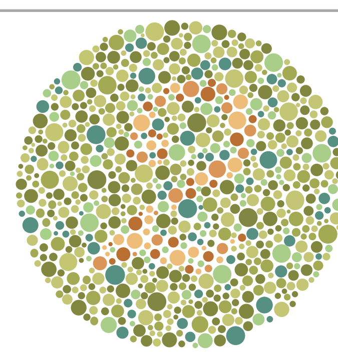

**Figure 5.** An example of an Ishihara card for colour blindness.

Oliver Sacks was also a pioneer in popularizing the study of the brain. Another popular writer and neurologist, Vilayanur Ramachandran, has spoken on the impact of Dr. Sacks' writing, describing his ability to 'connect seemingly unconnected disciplines, and inspire students to take up medicine and neurology'[13]. Atul Gawande, a doctor who writes about aging and death, attributes the humanity in Dr. Sack's books as his inspiration to write for a popular audience[14]. What may seem surprising and unfortunate is that many people in India haven't heard of Sacks, in spite of his being such a popular writer and having authored books that have been translated into over 25 languages (but not in any Indian language) globally[15].

> You can demonstrate the inheritance of colour blindness by using a simple family tree (pedigree chart) that simply traces patterns of inheritance without going into details of chromosomes, DNA, etc. Starting with a few people surviving a typhoon, you can use such a pedigree chart to easily demonstrate how island populations can become quickly inter-related due to marriages between relatives. If one of the initial survivors is totally colour blind, the pedigree chart can be used to demonstrate the high prevalence of total colour blindness in a few generations.

> The case of cycad-caused dementia can be used as an interesting example to introduce the concept of food chains.

Dr. Sacks died on 30th August 2015 due to complications arising from ocular cancer[16]. Even on his death bed, at age 82, Oliver Sacks couldn't resist the urge to tell a story. He wrote for the New Yorker magazine[17] on the memories of a fish dish his mother used to make when he was a child. In this article, you see the doctor coming to terms with the inevitable end to his life - a long journey of curiosity and discovery, deep empathy with people under his care and a knack for connecting to a global audience.

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## WE ARE WHAT WE REMEMBER:

# UNRAVELLING MEMORIES

BHAKTEE DONGAONKAR

The human brain never stops recording. It stores large amounts of information effortlessly. How does it achieve this? And, why are memories so important? This article provides insights to what encompasses memory and the role memories play in our lives.

Do you remember your first day at school? Try to visualize what your classroom looked like. What colour was your uniform? Who accompanied you to school? Were you crying? What did your teacher look like? Some of us have such a vivid memory of our first day at school that it can make us nostalgic even much later in life. If you cannot remember your first day of school, just relax! There is a biological reason behind this lapse in memory that I will explain a little later.

Try another example. Think of the best birthday you've ever had. How old did you turn that year? Did you cut a cake? What flavour was it? Do you remember the people who were part of your birthday celebrations? What were you wearing?

Reminiscences of the first day at school or a fun birthday are memories of events or specific episodes in one's life, and are thus called episodic memories. While significant episodes from our lives are remembered long after, like the ones highlighted in the examples above; insignificant ones, like what you ate for breakfast a month ago, are soon forgotten. Episodic memories are one kind of memory.

Are there other types of memory?

## Different types of memory

Long-term memories are of two kinds – explicit and implicit memories (Fig.1).

**Declarative (Explicit) Memories**

Any memory that requires conscious or deliberate effort to remember information is called a declarative memory. These memories can be explicitly recalled and verbalized, and make us aware of what we know and what we do not know. Explicit memories are of two types -

1. **Episodic memory** refers to our ability to remember details of time, place, the people involved, and specific activities that occur during an event. We absorb information from our surroundings by

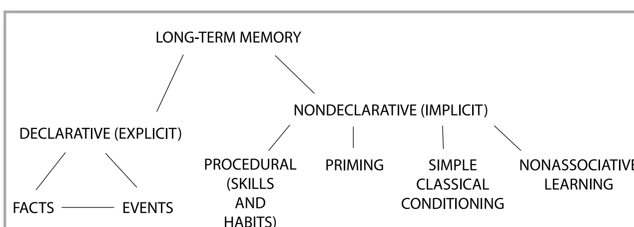


**Figure 1.** Classification of long-term memories.

continuously forming a series of episodic memories. Our memories of episodes from the past act as our references when we make decisions or solve problems.

2. **Semantic memories** refer to our ability to remember general knowledge and facts, such as, Tokyo being the capital of Japan, or plants making their food through photosynthesis. This type of memory contains schemas or rules of behaviour. For example, after going to the airport several times, we develop a schema for the actions that have to be taken at the airport – check in your baggage, collect boarding tickets, pass a security check and then board the flight. We develop several such mental schemas over a lifetime, which guide our behaviour and reduce the effort taken to complete a task or activity.

### Non-Declarative (Implicit) Memory

Implicit memories do not require conscious thought. They are elicited from experience, without reaching our awareness. They are of four types:

1. **Procedural memory** is responsible for our motor skills and habits, such as riding a bike, swimming or typing. The motor cortex (Fig. 2) in our brain coordinates directly with the muscles needed to execute these actions.

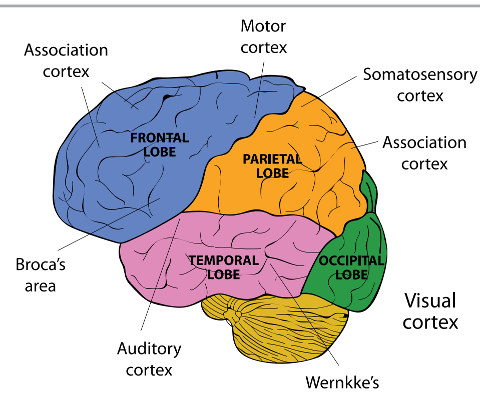


**Figure 2.** Cortices of the human brain.

2. **Priming:** Before you read ahead, try completing the words in the box below (Fig. 3).

| | |
|---|---|
| RED | PLUM |
| BLUE | NECTARINE |
| ORANGE | PEAR |
| YELLOW | APPLE |
| GR______ | GR______ |

**Figure 3.** Why do you fill different words in the two columns?

Here is a video with another example of priming: https://www.youtube.com/watch?v=5g4_v4JStOU.

Exposure to a particular stimulus influences our sensitivity and response to a later stimulus. Priming brings certain associations or thinking patterns to the forefront that influence our subsequent decisions, actions, or behaviours. In Fig. 3, the colour list primes 'green' while the fruit list primes 'grape' from their respective categories.

3. **In classical conditioning**, a new response is learned by making new associations. When two stimuli that were not related to each other are linked together, they can produce a learned response.

The most famous experiment of classical conditioning was demonstrated by Ian Pavlov, a Russian scientist. Pavlov's dog would salivate every time it saw food. One day Pavlov observed that the dog began salivating when he heard Pavlov's footsteps, much before seeing the food he'd brought. Pavlov decided to test this experimentally. He struck a bell before giving the dog his food every time. Over the next several meals, the dog learned to associate the ringing of the bell with arrival of food. So the dog began salivating when the bell was struck, much before the food was brought into sight. Thus a neutral stimulus, such as the ringing of a bell, was associated to the involuntary response of salivating. Other such involuntary responses include crying, laughing and freezing.

Watch two more videos of classical conditioning in humans: https://www.youtube.com/watch?v=Eo7jcI8fAuI https://www.youtube.com/watch?v=OwBQIhg6CvE .

4. **In non-associative memory**, repeated exposure to a stimulus increases or decreases the response to that stimulus. When the response to a stimulus decreases, it is called habituation. For example, while sitting in a library to read, you are startled by the sudden sound of a loud bang. You figure out that some construction has begun on the floor above, and when the banging continues, you are less distracted by it. Gradually, you are able to ignore the noise, and continue reading. What happens in this case is that you become habituated to the noise. On the other hand, when a response to a stimulus increases, it is called sensitization. For example, while trying to sleep, you hear a water faucet leaking. Every drop that

falls makes a sound which increasingly draws your attention to it, and stops you from falling asleep.

Both these examples are over short time scales, but habituation and sensitization can also occur over larger time scales and result in long lasting changes in behaviour. One example of long term habituation can be seen when we travel across time zones. Our body is jetlagged for the first few days, but after that we gradually settle into the day and night routine of the new time zone. An example of long-term sensitization would be a war veteran dropping to the ground on hearing a sudden sound, like the bursting of a car tyre, and responding as if a gun had been fired.

## How does our brain form a memory?

Our identities are formed based on our recollections of the many different episodes/events that we experience in our lives. It is through our ability to form episodic memories that we are able to recollect both the good and bad events from our past. Keeping in mind the role of episodic memories in defining us, let's take a look at how these memories are formed.

Imagine that you witness a road accident while travelling in a bus. The sensory information that you see and hear is processed first. The visual information entering the eye travels to the back of your brain to the visual cortex in the occipital lobe (Fig. 2). The brain cells or neurons of this area are specialized to process information such as shape, size, colour and movement. Similarly, the neurons in the auditory cortex located at the crossover area between medial, frontal and parietal lobes (Fig. 2) analyse different sounds. The processed visual and auditory information travels to the temporal cortex where objects, people and sounds are identified. Simultaneously, the parietal cortex assesses the relative location of the objects and people around you. All identified information is then bound together by the 'hippocampus', named after the sea-horse or sea monster in Greek mythology that it resembles in shape (Fig. 4), to form an episodic memory. Each of us has two hippocampi, situated deep inside the temporal lobes on either sides of the brain, behind both ears (Fig. 5). While the hippocampi do not store any information within themselves, they play an important role in forming, storing and retrieving details of events. Each hippocampus functions like a library catalogue - it maintains the location for every memory it has helped form. So where is the memory of an event stored?

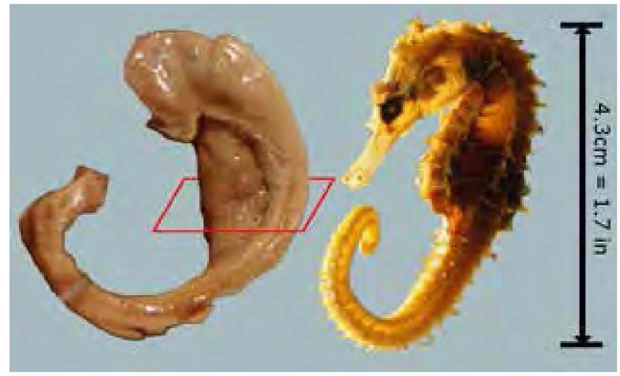


**Figure 4.** The human Hippocampus (left) and the seahorse (right) look very similar.

A memory is represented in our brain by groups of neurons. Neurons group together if they process information at the same time. In the example of a road accident, the visual information (e.g. an injured person), auditory information (e.g. people running, ambulance arriving, etc.) and location of the accident, are all processed simultaneously by neurons in different regions of the brain. Those neurons became active at the same time and, therefore, together form a memory.

The connections between groups of neurons forming an episodic memory are controlled by the hippocampus. When we recollect such an episode in the future – say a few days or weeks later, the hippocampus makes the particular group of neurons active again and we remember events as though we are reliving them.

Typically, the hippocampi are not very well developed at birth. At around age 2, the hippocampi begin to mature and connect with other brain regions. That is why infants and toddlers are unable to remember many events or episodes from their lives. By the age of 4,

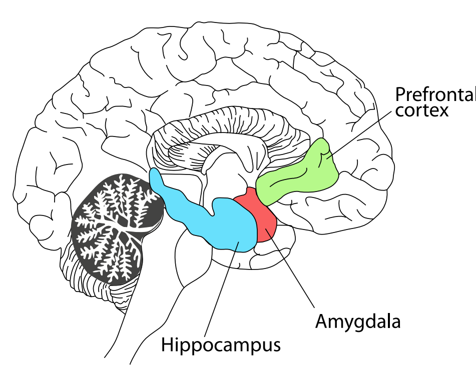


**Figure 5.** The hippocampus and amygdala are situated bilaterally, deep inside the medial temporal lobes of the brain.

**The Case of HM**

Henry Gustav Molaison (February 26, 1926 – December 2, 2008), called as H.M., by researchers, was the most studied patient in the history of neuroscience. For more than 50 years, his unique case helped scientists to study memory. At age 7, HM was knocked down by a bicycle that resulted in seizures or epileptic attacks, which worsened after he turned 16. He could not lead a normal life. Dr. William Scoville, a neurosurgeon at Hartford Hospital, Connecticut, USA recommended a surgical treatment for his epilepsy. Removing brain tissue within HM's bilateral medial temporal lobes would control his seizures. That surgery left HM, then 27 years old, with severe memory problems. He could remember his name, family and childhood but he could not remember his day-to-day activities. Neither could he remember his doctor who visited him daily. That left Dr. Scoville baffled because he had never come across such a patient. Dr. Scoville then invited Dr. Brenda Milner, a clinical neuropsychologist, to study HM. Dr. Milner had worked with similar patients but none of them showed symptoms that were as severe as those in HM. Over many years of testing HM, her team found that HM's intellectual abilities were intact. He could remember facts and general knowledge. He could also learn motor skills (like tracing a star by looking at its mirror reflection) over many practice trials, but was never conscious of these learning sessions. Her efforts over years of tests on HM revealed that HM found it difficult to remember events from the past few years (retrograde amnesia) leading up to his surgery. Neither could HM form new memories (antero-grade amnesia), which is why he could not remember his doctor. He lived only in the present. Dr. Scoville and Dr. Milner pieced together this puzzle to conclude that in an effort to curb HM's seizures, Dr. Scoville had removed the 'hippocampus', a specific region within the medial temporal lobe that is important for forming, maintaining, and retrieving long-term memories.

Source: Squire, L. (2009). The legacy of patient HM for neuroscience. Neuron, 61(1): 6–9. Big Picture: Inside the Brain (2013). Published by the Wellcome Trust, a charity registered in England and Wales, no. 210183. bigpictureeducation.com.

children begin to slowly recollect events and verbalize what they remember, but not as well as adults. This is probably the reason why many of us cannot remember events from when we were kids, such as our first day at school. Our hippocampi were still developing at that age, and the memories that were formed then did not last very long.

Suggestive of its role in learning and memory, the hippocampus is also the only region of the human brain that undergoes 'neurogenesis' (the ability to generate new cells over one's lifetime). This is in contrast to the rest of the brain, which has the same number of cells from birth until death. We owe our ability to continuously learn and remember large and diverse amounts of information to hippocampal neurogenesis.

## What affects our memories?

With time and regular overnight sleep, newly formed memories are consolidated and stored as long-term memories. With poor or no sleep, our memory-making mental processes are badly affected because the rhythms of brain activity during sleep provide an environment for neurons to make new connections within the brain. It is these new connections that give us the ability to make inferences, be creative, and generate knowledge and ideas.

Memories do not last in the same form forever, they change with time. Some fade slowly and eventually we forget them. Some are updated with new information, like in our understanding of concepts of math and science, which continuously evolve.

Emotions and stress can affect our ability to learn and remember. Emotions are regulated by the 'amygdala', a brain structure located adjacent to the hippocampus (Fig. 5). The amygdala processes all kinds of emotions, and also sends signals to the hippocampus about how positive or negative the individual felt at the time of learning or recall. Neurotransmitters or neuro-chemicals released in the brain during negative emotional states can impair our ability to learn and recall. That is why when you are stressed about writing an exam you sometimes struggle to remember even things that you otherwise remember well. In contrast, a traumatic experience can evoke such a powerful emotional response that it protects that particular memory of a trauma for life. An example of a traumatic experience could be of an accident in which you barely escaped with your life, but lost a family member. The difficulty in forgetting traumatic experiences can sometimes cause emotional or stress disorders in people.

## What if we had no memories?

As discussed before, implicit memories do not require conscious or deliberate thought while explicit memories do. With conscious thought, we can relive our past, experience the present, and imagine the future. In other words, we can mentally travel in time. This ability depends critically on episodic memories, which are controlled by the hippocampus.

What if we had no hippocampi? This is answered by the case of a patient with missing hippocampi, known to researchers as HM (see Box 1: The Case of HM). Without hippocampi, HM struggled to recollect his past, and was unable to form new memories, or think about his future. This ability to mentally travel in time makes us conscious beings, a uniquely human trait.

## Conclusion

While memories arise from our experiences in life, decades of research show us that our memories are not permanent; they change in form and/or accuracy. Current research is focussed on exploring all possible factors that can cause a memory to be altered. Knowing these factors can help provide therapy to people who suffer from memory disorders.

What we do understand, however, is that our memories are essential to us. We use them to draw references from the past to plan and predict our future. Both good and bad memories help shape our thinking, decision-making and problem-solving abilities. While negative experiences remind us of what can be detrimental and needs to be avoided; positive experiences encourage us to show certain other behaviours.

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## Feathers and Warm Blood: Dino facts that you didn't know

*– Vignesh Narayan*


The different kinds of birds found today trace their ancestry back to dinosaurs. About 66 million years ago, a mass extinction event (probably an asteroid hitting the earth) decimated most of the dinosaur population.

The few that were left evolved into the birds that we see today. What few people know is that over the past two decades, archaeologists have unearthed thousands of fossils of dinosaurs that had feathers!

'Proto-feathers' or primitive feathers have been found on the fossils of a variety of dinosaurs, from meat-eating bird ancestors to plant-eating dinosaurs that were wiped out in the extinction event.

Using information from fossilized pigment cells, even the colour of the feathers of some dinosaur species have been worked out! According to researchers at the Yale university, Anchiornis huxleyi, a feathered dinosaur that lived during the late Jurassic period in China, sported grey plumage, a reddish Mohawk and white feathers on its wings and legs, which ended in black tips.

If feathers were not enough, researchers have used different types of measurements on the fossils of dinosaurs to conclude that the body temperatures of these gigantic creatures were between 36°C and 38°C, making them warm-blooded animals like birds, and not cold-blooded like the reptiles that we have today.

We are moving away from an image of dinosaurs as large cold-blooded reptiles. Instead we are beginning to see them as warm-blooded and brightly coloured animals that used feathers to fly and attract mates, much like birds do today.

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# WE HAVE COMPANY: HOW GUT BACTERIA INFLUENCE HEALTH & DISEASE

GAGANDEEP KANG

The gut environment is complex, with different amounts and types of micro-organisms along its length. What role do commensal intestinal micro-organisms have on homeostatic mechanisms in health and development of disease? This article explores some of these emerging frontiers in our understanding of gut bacteria.

Discoveries made in the last five years or so have shown that we are introduced to micro-organisms even before our birth. Contrary to earlier belief that the mother's womb protects a developing foetus against micro-organisms, we now know that bacteria from the mother's blood can enter the amniotic fluid (that surrounds the developing foetus). The type and numbers of these bacteria have a huge bearing not only on pregnancy outcomes but also on the immune system of the new-born. Our association with microbes becomes more rapid at the time of our birth. A new-born is exposed to micro-organisms in almost everything it makes contact with – its mother's birth canal, skin and breast-milk; other food; and the environment. All its exposed surfaces, including its skin, eyes, ears, reproductive tract and gut, are quickly colonised by microbes. The nature and size of these initial microbial populations can vary initially with changes in diet and environment, but as a child grows older, these microbial communities become more stable in composition. The gut of an adult has over thousands of species of micro-organisms of all kinds – bacteria, fungi and viruses, and contributes nearly 2 kilograms of her body weight!

> **Colonisation:** This is the process by which microbial cells multiply to establish a 'colony' after entry into the body. Usually, different microbial species abound in different parts of the body - bacteria on teeth surface are different than those on the cheek, which in turn differ from those colonising the tongue, etc.

Since Antonie von Leeuwenhoek published his work in the early 1700s, scientists have known that micro-organisms are found at various sites in the human body, particularly the gut. We've also known that not all microbes that are found at a particular location are permanent residents; some only appear transiently. Those that are permanent residents establish long-term interactions with their host, forming stable populations that may have demonstrable functions.

Recent research has begun to demonstrate just how complex some of the interactions between

Antonie von Leeuwenhoek: Widely considered to be the 'Father of Microbiology', Leeuwenhoek was, in many ways, an unlikely scientist. A tradesman by profession, he had no money, no degree; and the only language he knew was his native - Dutch. Despite these disadvantages, he made some of the most seminal discoveries in Biology. Grinding lenses, he made simple microscopes — 500 of them over his lifetime! He discovered sperm cells, blood cells, bacterial cells on teeth scrapings, as well as microscopic rotifers and protists.

microorganisms and their host **really** are. Improvements in laboratory science and (animal) model systems are helping us understand some of the mechanisms by which human–microbial interactions occur, and how they influence health and disease in their human hosts.

## How are intestinal microorganisms studied?

Understanding our relationship with intestinal micro-organisms depends upon identifying the types and numbers of the different micro-organisms in the gut; and the nature of interactions between different micro-organisms, as well as between micro-organisms and our bodies.

The conventional approach to doing this would involve isolating individual microbial species from the gut, and inducing them to reproduce under controlled laboratory conditions (popularly called microbial culture, or simply 'culture'). A variety of physico-chemical and biological tests would then be used to uniquely identify these colonies, in a process that is somewhat similar to identifying human beings based on their facial features. This approach has limited uses, however, because we have not been able to grow the many microbes that thrive in the low- (or no-) oxygen environment of the human gut under laboratory conditions.

**Microbiota**

This term refers to the collection of micro-organisms that are found at a particular location, for example, the skin of an individual or an ocean vent.

In contrast, recent advances in genetics have made it possible to identify these micro-organisms by their nucleic acids in a process akin to fingerprinting in humans. Also, gnotobiotic, knock-out, transgenic and humanized mice models are helping us decipher the cross-talk between gut microbes and their human hosts.

**Animal models in characterising gut microbiota**

**Gnotobiotic** (from Greek *gnostos*, known; and *bios* meaning life) refers to a laboratory animal, commonly a mouse, whose microbial composition is known in its entirety. These animals are raised in germ-free environments, and then introduced to one or a few species of micro-organisms in a controlled manner under laboratory conditions. The effects of this specific kind of colonization on the gnotobiotic animal are used to understand similar interactions in humans or other hosts of the microbes.

**Knock-out** is a laboratory-raised mouse in which a specific gene has been inactivated, or 'knocked out'. Evidence suggests that the genetic background of individuals – the presence/absence of certain genes - influences the composition of their gut microbiota. Scientists can investigate this by evaluating the effects of knocking-out the mouse counterparts of specific human genes on the composition of their gut microbial communities.

**Transgenic** is any plant or animal with gene(s) from another organism inserted into its genome. This kind of insertion can either happen naturally (for example, genes from disease-causing bacteria found inserted in the DNA of hundreds of varieties of sweet potato), or by deliberate human intervention.

**Humanised** mice are mice with transplanted human faecal microbiota in their guts. These are compared with normal mice to identify the role of intestinal micro-organisms in human metabolism.

Thus, information is now emerging not only on 'who is there' in the gut, but also on 'what are they doing?' With an improvement of methods to study them, we are now able to characterise not just the diversity of microorganisms in the gut, but also their interactions and functional stability.

## Microbial communities in the human gut

Much of our early information on colonisation came from studies of aerobic and anaerobic bacteria that could be cultured in labs. These studies have shown us that the human gut is differentially colonized, with the number and diversity of bacteria in it increasing progressively. Thus, for every milliliter of its contents, the stomach has ~10,000 bacterial cells, the small intestine (ileum) has substantially higher density than this (~108 bacterial cells/ml), and the distal colon houses even greater numbers, ~1013 bacteria/ml. To add to this complexity, different bacterial species dominate different locations of the gut, with *Helicobacter* spp. found in the stomach, facultative anaerobes and strict anaerobes in the ileum, and predominantly anaerobic bacteria in the distal colon. What's more – the composition of microbial communities in the human gut can vary over the lifetime of an individual and up to as much as 30% between individuals.

Based on the composition of their gut microbiota, a research study in 2011 classified all humans into three categories or 'entero'-types. Humans belonging to the first category, and called Type I entero-types, have high levels of *Bacteroides* species, and thus also of the enzymes for synthesis of biotin (Vitamin B7) that these bacteria produce. Type 2 entero-types have less *Bacteroides* spp. but more *Prevotella* spp., and, therefore, more enzymes for thiamine (vitamin B1); while Type 3 have high levels of *Ruminococcus* spp.

## Diet and the intestinal microbiota: you are what you eat

The relationship between intestinal microbiota and their host is strongly influenced by the diet of the host.

By acting as substrates for microbial metabolism, the nutrients we consume play an important role in altering the structure of microbial communities in the gut. One example of this is seen in the fact that when compared to formula-fed infants, breastfed ones show higher levels of bifidobacteria. Bifidobacteria have multiple health-related benefits in a newborn, such as the protection of the gut mucosa, increased production of immunoglobulin A, and the ability to metabolise carbohydrates in breast milk.

Similarly, another study compared the intestinal microbiota of children in rural Burkina Faso in Africa, with children in Europe. While the diet of the African children was rich in complex carbohydrates, fibre and non-animal protein, that of their European counterparts was rich in animal protein, sugar, starch and fat. This study showed that children in Burkina Faso had greater microbial richness, more *Prevotella* and less *Bacteroides*, and produced higher levels of short-chain fatty acids than children in Europe. Other studies have shown that greater microbial richness is associated with diets higher in fruits, vegetables and fibre; while lower richness is associated with multiple diseases — obesity, insulin resistance, dyslipidemia (abnormal amounts of lipids in blood) and inflammatory disorders.

Apart from influencing their composition and/or richness, diets can also alter the metabolic functions of intestinal microbial communities in humans. Intestinal bacteria digest many types of food to produce small molecules that are then metabolised in the human liver, and have an important role in human physiology. For example, carbohydrates in starch can be broken down by colonic bacteria to produce short-chain fatty acids, which regulate several functions related to immunity and lipid synthesis.

## Intestinal microbiota in health and disease

Although there are differences between the intestinal microbiota of different individuals, in general more than one microbial species can perform a single metabolic function in the human body. This means that in spite of differences and changes in the number, type and proportions of individual microbial species, their human hosts can continue to have normal gut function.

Gut microbiota and the host adapt to each other through some very interesting evolutionary and molecular processes. One example of this is seen among the Japanese. Sushi, a dish made by wrapping rice and raw fish in nori (derived from seaweed), is an important part of the Japanese diet. Nori is the only food humans eat which contains a special class of complex carbohydrates called porphyrans. We know of only two organisms with enzymes, called porphyranases, capable of breaking down porphyrans. One of these is a marine bacterium, called *Zobellia galactonivorans*, which naturally grows on seaweed. The other is a gut bacterium, called *Bacteroides plebeius*, found only in the intestines of the Japanese. It seems likely that this human gut bacterium acquired the genes for porphyranases from *Zobellia* ingested along with the seaweed that forms part of the regular diet of the Japanese. By acquiring these genes, gut bacteria are able to break down the carbohydrates of the seaweed, thus exploiting an additional source of energy.

**Useful Websites**

http://academy.asm.org/index.php/faq-series/5122-humanmicrobiome

http://www.gutmicrobiotawatch.org/en/gut-microbiota-info/

Extensive research on the microbiota shows that intestinal bacteria modulate genes involved in several different intestinal functions in humans, including nutrient absorption, carbohydrate metabolism and intestinal motility.

### Preventing infection: The barrier function

One of the most significant benefits we derive from resident gut microbiota is that these microbes act as a defensive barrier against potential pathogens. They do this through a variety of mechanisms, one of which involves the production of antimicrobial substances that are active against several intestinal pathogens. For example, *Lactobacillus* and *Bifidobacterium* spp. produce antibacterial substances active against a wide range of pathogens including entero-pathogenic *E. coli*, and *Listeria monocytogenes*, etc. Other mechanisms used by gut bacteria to prevent pathogen colonization include impairment of flagellar motility and prevention of cellular damage in the host.


**Figure 1.** An electron micrograph of a cluster of *E. coli*, magnified 10,000 times. Source: Photo by Eric Erbe, digital colorization by Christopher Pooley, both of USDA, ARS, EMU, Wikimedia Commons. License: Public Domain. URL: https://en.wikipedia.org/wiki/File:E_coli_at_10000x,_original.jpg

### Nutrient uptake

One of the most exciting findings about the host-microbe relationship in recent years has been the role of the intestinal microbiota in malnutrition.

The relationship between the microbial flora of the gut and the host depends on the capability of either or both partners to utilize nutrients in human diets. Does this mean that gut microbes actively compete with us for nutrients from our food? On the contrary, experiments comparing the calorie intake of conventional and germ-free mice show that the former require 30% less calories to maintain their body weight. This indicates that gut microbes help us derive the maximum nutritional value from available nutrients.

Several studies link gut microbiota to obesity and malnutrition. In one of these studies, germ-free mice put on weight when they were transplanted with gut microbes from an obese person, but not those from a thin person. It was also possible to use the gut microbiota from a thin person to displace the microbiota of obese mice. As long as they were put on a healthy diet, this transplantation could prevent the obese mice from gaining weight. In another study, faecal samples were collected over a long period of time from twins in Malawi, a landlocked country in south-eastern Africa that has one of the highest infant mortality rates in the world. Results from this study, published in 2013, showed that the gut microbiota of children suffering from a severe form of malnutrition, called Kwashiorkar, was very different from that of unaffected peers of the same age-group. When the microbiota of the malnourished children was transplanted into gnotobiotic mice fed with Malawian diets, they lost weight, and showed an altered amino acid and carbohydrate metabolism. A similar study by the same group, conducted in Bangladesh, showed that the gut microbiota of malnourished individuals were typically like that of much younger individuals, or 'immature'. Symptoms of malnutrition could be reduced slightly by therapeutic feeding, with malnourished individuals showing temporary maturation of their gut microbiota, but soon reverted to their previous 'malnourished' state. Studies to explore whether therapeutic food could lead to a more permanent maturation in gut microbiota are currently underway.

With diets that primarily consist of carbohydrates, humans are well-equipped to digest disaccharides, as well as absorb the monosaccharides produced as a result. However, our capacity to hydrolyse and utilise other complex polysaccharides, particularly those of plant origin such as cellulose, xylan and pectin, is limited. These carbohydrates can be digested by some anaerobic bacteria that reside in in our distal colon. Equipped with specific enzymes for degradation of complex polysaccharides, these microbes break down undigested dietary carbohydrates to short chain fatty acids that can then be utilized by different organs of our body. Thus, commensalism or 'eating together' helps gut microbial communities derive energy from us, while we benefit from this association by utilizing otherwise indigestible carbohydrates.

## Disease states and the microbiota

While several studies have shown that a new-born's immune system co-evolves with the microbial community in her gut, gut microbiota may also contribute to some diseases, like atherosclerosis (or a hardening of arteries), by breaking down dietary lipids to harmful metabolites. Similarly, gut microbes have been shown to break down another dietary component – choline, to produce trimethylamine oxide, a small molecule that is strongly associated with an increased risk for coronary vascular disease in humans.

There is evidence that the gut microbiota also contributes to several forms of liver disease including non-alcoholic fatty liver disease, alcoholic and auto-immune liver disease. Similar associations between altered gut microbiota and disease states are also found in inflammatory bowel disease, diabetes and colon cancer. The mechanisms by which gut microbes cause these different diseases are still being investigated.

## Using microbiota for treatment - faecal microbe transplants

While they can contribute to diseases in the host, gut microbes can also be used to cure certain ailments.

*Clostridium difficile* is an anaerobic bacterium that is commonly found in the gut. However, the use of antibiotics or a severe inflammation of the large bowel in hospitalised patients can lead to an overgrowth of *C. difficile*. This can result in severe diarrhoea (up to 15 times a day), abdominal pain, weight loss, fever, and even be fatal. Even when treatment with antibiotics is initially successful, the infection can recur. This is believed to be due to the inability of the intestinal microbiota to suppress the growth of the toxin-producing *C. difficile*.

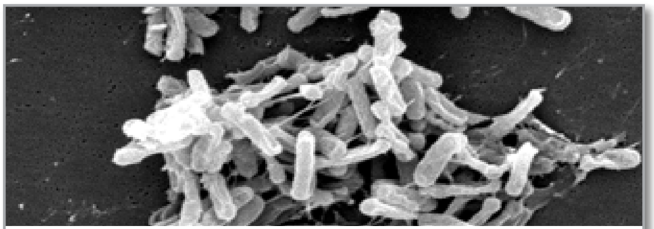

**Figure 2.** Scanning electron micrograph of *Clostridium difficile* from a stool sample. Source: CDC/ Lois S. Wiggs (PHIL #6260), 2004, Obtained from the CDC Public Health Image Library, Wikimedia Commons. License: Public Domain. URL: https://en.wikipedia.org/wiki/Clostridium#/media/File:Clostridium_difficile_01.jpg

Recently, Faecal Microbiota Transplant (FMT) has begun to be used to treat this recurrent condition with some success. FMT is a procedure in which faecal matter, or stool, is collected from a tested donor, mixed with a saline solution, and placed in a patient's gut through an enema or an endoscopy. Faecal transplants have also had good results with other digestive or auto-immune diseases, including Irritable Bowel Syndrome and inflammatory bowel disorders.

## Conclusion

In the past decade, there has been increasing interest in the human microbiota, and new methods and tools are being developed to enable more detailed studies. One important reason for this interest has been the recognition that the commensal microorganisms comprising human microbiota are more than just passengers in the host, and may actually regulate certain vital host functions. With a better understanding of the contribution of intestinal microbiota to specific disease states, it may be possible to develop new strategies or drugs to modulate these microbes to treat or prevent diseases.

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# RECONSTRUCTING THE HISTORY OF LIFE
# A GENETIC APPROACH

KRISHNAPRIYA TAMMA

There are 7 billion people, more than 100 trillion ants, and more than a billion honey bees in the world. Where did all this diversity come from? How did we evolve - what's the human story? In this article, the author explores some of the ways in which we've tried to answer these questions.

Humans have always been curious about the origins of life on earth. Many theories and explanations have been offered over the course of human history. When Darwin and Wallace first presented the theory of evolution by natural selection, it led to a great deal of controversy. However, today there is indisputable evidence for this theory. Evolution, according to Darwin, proceeded through '**Descent with modification**', which simply denoted the passing of traits from parent to offspring, albeit imperfectly. Offspring, while being largely similar to their parents, may show some differences. Over time, these differences may be selected and result in a divergence strong enough for a new species to be formed. This new species is still related to the older one, since it is derived from it. Just like my cousin and I share a common ancestor in the form of a grandfather, species too share common ancestors with other related species. Going sufficiently far back in time, we can actually trace the ancestor for all life on earth (about 3.8 billion years ago). Therefore, we can reconstruct the history of life on earth by carefully reconstructing relationships between species.

**Phylogenetics is the field of biology that focuses on the reconstruction of relationships between different species, and the reconstruction of evolutionary history of lineages.** Such phylogenetic trees or phylogenies (refer Fig.1) can be constructed using morphological or genetic data. But, thanks to advances in the field of genetics, genetic data or DNA-based information has given us greater power to reconstruct relationships, even amongst very closely related and morphologically similar species.

An organism's **genome** is its complete set of DNA, including all of its genes. A copy of the entire genome of an organism – more than 3 billion DNA base pairs in humans – is found within each cell of its body. Each copy of the genome contains all the information needed to build and maintain the entire organism.

**DNA, the blueprint of life, is double stranded.** Deoxyribonucleic acid is a molecule that carries genetic instructions for growth, development, functioning and reproduction of all known living organisms and many viruses. Most DNA molecules consist of two antiparallel biopolymer strands coiled around each other to form a double helix. Much like proteins are polymers of amino acids, each of the two DNA strands is a polynucleotide, or a polymer of nucleotides. Each nucleotide is composed of a phosphate group, a sugar called deoxyribose, and one of four nitrogen-containing nucleobases – cytosine (C), guanine (G), adenine (A), or thymine (T). The sequence in which these appear within a DNA molecule dictates the sequence of amino acids in proteins. The nucleobases on one strand pair up with bases at corresponding positions on the other strand to form **base pairs**.

A **base pair** in DNA is of two types: A-T or C-G. The nucleotides in a **base pair** are complementary which means their shape allows them to bond together with hydrogen bonds.

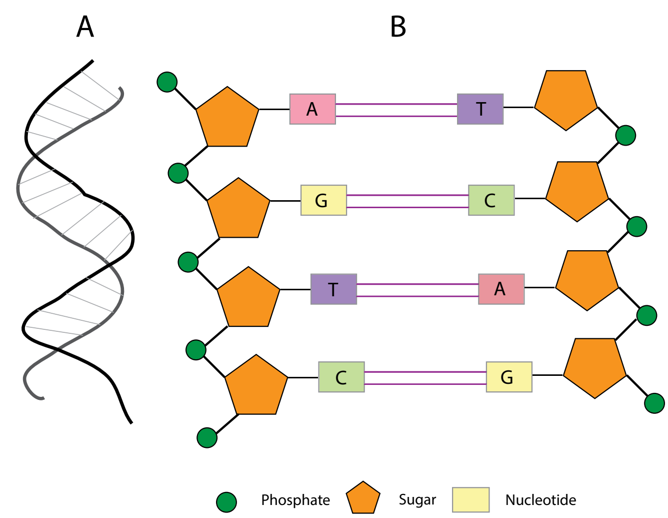


**Figure 1.** The structure of DNA.

A **gene** is a locus (or region) of DNA that encodes a functional RNA or protein product, and is the molecular unit of heredity. The transmission of **genes** to an organism's offspring is the basis of the inheritance of phenotypic traits.

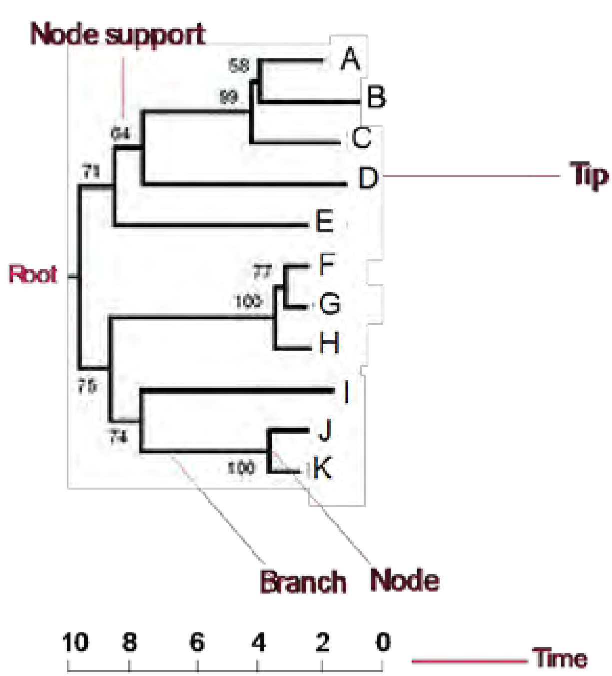
How is this done? By comparing the sequence of nucleotides in the genomes of any two organisms, we can calculate the genetic variation within, and between, the species they belong to. This variation is measured in terms of their genetic distance, and represents the number of bases (A, T, G and C) that are similar (and dissimilar) between the two organisms/ species. Through special computer programs, these genetic distances can be used to build a phylogenetic tree of relationships. In general, the genetic distance between two taxa is inversely related to their degree of relatedness. Thus, the value of genetic distance is lower between closely related taxa, and higher between distantly related taxa. This information can be used not just to build relationships between different species, but also to understand how different populations of species are related to each other. Can this tell us anything about the evolution of humans?

## How to read a phylogenetic tree

A phylogenetic tree is a diagrammatic representation of the relationships between taxa (Fig. 2). Species that are closely related are closer to each other on a tree, and are linked by fewer branches. Let's break down a phylogenetic tree to understand this better. The first thing that we notice is the overall shape of the phylogenetic tree - the overall branching pattern of the tree is called its 'topology'. At the base of the tree is the 'root'. An out-group, one that is not within the lineage being examined, is necessary to root the tree. The out-group provides a reference point which can help clarify the relationships between species in the 'ingroup' (the one we are interested in) better. The 'tips' refer to the species being compared, and are connected to other tips by 'branches'. The 'internal nodes' refer to the ancestors from whom two or more descendant species diverge. The nodes represent the point at which the two tips shared a recent common ancestor. From the ancestor, two new species (or generally lineages) are born. Thus, nodes also represent inferred speciation events. Taxa (tips) that share a common ancestor are said to be 'sister' to each other.

For instance, to a casual observer the bonobo and chimpanzee, our primate cousins, look very similar. However, genetically they are quite distinct. In the ape tree (Fig. 3), humans, chimpanzees, bonobos, gorillas and orangutans represent the tips. All apes share a common ancestor that diverged from other primates. While chimps and bonobos are sisters to each other, humans too share a common ancestor with both of them. So that's how we are related to primates! How long ago did this common ancestor between humans and primates exist?

**How to read a phylogenetic tree?**




B is the closed relative of A; A and B are called 'sisters'
They share a common ancestor with C

The root of the tree represents the ancestral lineag from which all lineages descended

The numbers on the nodes refer to the node support.
This is a way to evaluate the con dence in the tree

The horizontal scale represents time in million years ago. Zero refers to present
The root of the lineage is dated to about 10 million years ago

**Figure 2.** How to read a phylogenetic tree.

## Finding age on the 'tree of life'

Not only does a phylogenetic tree allow us to reconstruct relationships between different taxa, but it also allows us to infer the timing of certain evolutionary events, through a process called 'divergence dating'. Divergence dating is a method based on the molecular clock hypothesis, which suggests that mutations are accumulated over time at some uniform rate. By calculating the number of base differences between the genomes of two species, we can use our knowledge of the rate at which these differences have accumulated to estimate the time when the two lineages split. Although there is no fixed rate at which sequences evolve, we can model the rate as a distribution (say a normal distribution) to estimate divergence (fossils are often used to calibrate the tree since they provide an independent reference age for a clade; ancestor + descendants = clade).

One example of divergence dating can be seen in the primate tree (Fig. 3) which shows us that the chimpanzee and human lineages split about 4-5 million years ago. This means that the human lineage, of which *Homo sapiens* are the sole surviving species, must most likely have evolved around 5 million years ago. Fossil records confirm this. They also show us that although many species of *Homo* evolved between 5 million years ago and now, including *Homo neanderthalensis*; all except *Homo sapiens* have become extinct.

**Lineage:** A lineage is defined as any continuous line of descent; any series of organisms connected by reproduction by parent of offspring.

**Speciation:** Speciation describes evolutionary process by which populations become reproductively isolated, eventually leading to the formation of two separate species. Species often diverge from a common ancestor. As they diverge they accumulate mutations, ultimately becoming reproductively isolated – meaning that the individuals of the two groups cannot breed successfully. Reproductive isolation is considered a necessary condition for speciation.

**Mutation:** Every time a cell replicates, its entire genome is copied. In some cases, there are errors in copying, which result in incorrect nucleotide being inserted into the copies. These changes in the genome are called mutations. Often mutations can change the amino acid that they code for, resulting in changes to proteins.

What if we were able to expand the scope of what we've done with the primate map, and construct a dated tree that shows us how all known species on Earth are related to each other? A project called the Tree of Life aims to do exactly this with molecular data, and using some of the most advanced genetic and computation methods. What is interesting is that Darwin and subsequent evolutionary biologists have largely viewed relationships in the form of a 'tree of life'. But recent advances in our understanding of horizontal gene transfers, involving exchange of genetic material between long-diverged species, make it increasingly likely that all life may actually be related to each other through Web of Life scenarios. This is especially true of prokaryotes.

Do we have all the data we need for completing the Tree of Life? Although we have data today for many more species than ever before, we are still discovering many new species that we did not know of before. Even amongst the species that we know of, there are many from the tropics for which we have no genetic data.

What can we learn from the Tree of life? One can observe startling differences in the distribution of lineages across the Tree of Life, imperfect though it may be. Some clades have a high diversity of lineages, while some others may be represented by a single species. These differences in richness may have been caused both by intrinsic (biological) and extrinsic (historic effects). For instance, small mammal lineages including Rodentia (rats and mice) and Chiroptera (bats) are amongst the richest of mammal lineages. This is probably a result of their small body size and high reproductive rates. Added to this, certain historical factors could have also resulted in rapid evolution and speciation in some groups. For instance, it is believed that the spread of the grasslands in Oligocene (35 million years ago) led to the evolution of hypsodonty (high-crowned teeth) and increase in diversity of animals that showed hypsodonty.

**Clades:** Derived from the Greek word "klados", meaning branch or twig. A clade is a monophyletic taxon; or a group of organisms which includes the most recent common ancestor of all of its members, and all the descendants of that most recent common ancestor.

**Prokaryotes:** Single-celled organisms that lack nucleus and other membrane-bound organelles.

Thus, phylogenies not only help us reconstruct relationships, they also allow us to investigate the mechanisms through which biodiversity is accumulated. In Fig. 4, we can see that some clades are more diverse (have more species) than others,

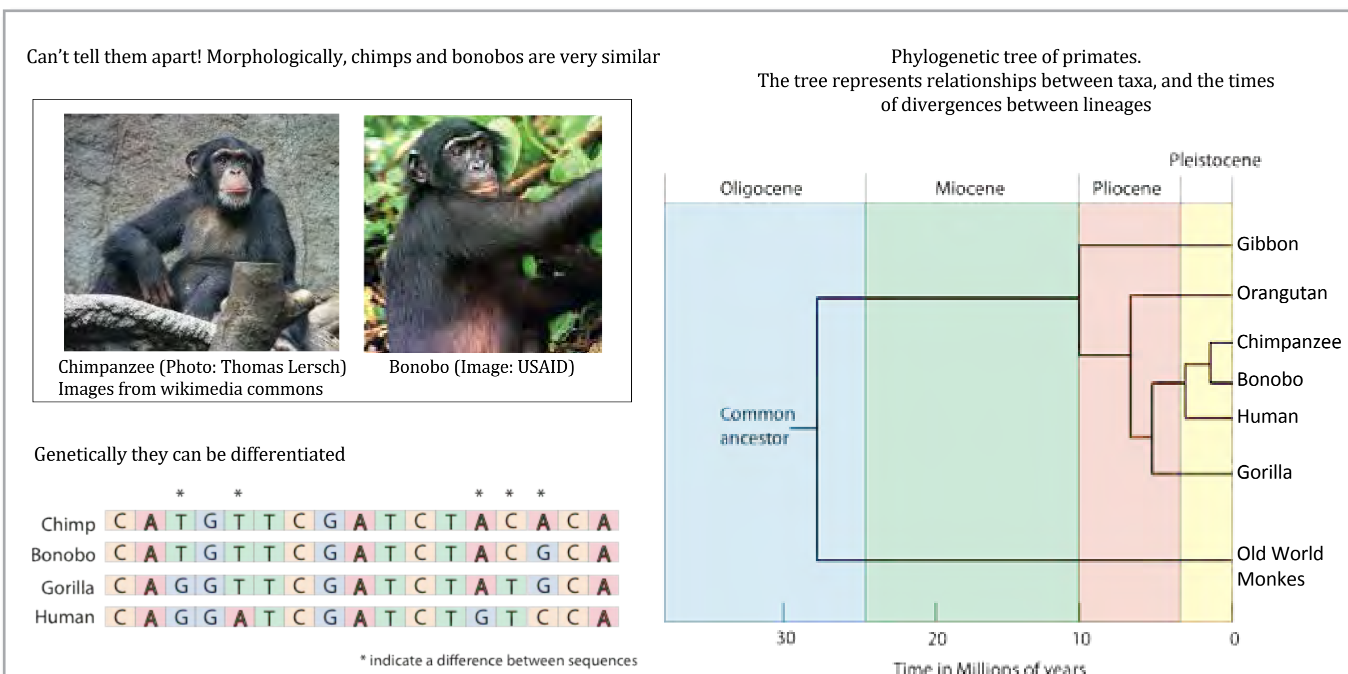



**Figure 3.** How do we reconstruct relationships between primates?

and that some clades are much younger than others. Studying the spatial and temporal differences in the rates of diversification processes (speciation and extinction) helps us understand how biodiversity is built up. Although, we still haven't mapped the evolutionary history of the majority of life on earth, the explosion of genomic data has now given us much more power to detect and evaluate diversity. Instead of focusing on a few genes at a time, we can now look at almost the entire genome of a species. This gives us unprecedented access to the genetic history of species, allowing us to detect the historical factors that shape a species/individual across all time scales - past to present. While still in their infancy, a variety of methods are now being developed to generate phylogenies from such data.

## What about patterns within species?

Stand at the bus depot anywhere in India and you can see a great diversity of people. India is just a microcosm for global diversity. There is enormous diversity within humans across the world - in terms of hair, skin colour, face structure and other morphological features. But, how diverse are we exactly?

Despite our very visible morphological diversity, humans show much lower genetic diversity between populations than chimps do! However, there are some clear geographic patterns in the distribution of genetic variations within human populations. **The study of how genetic variation within a species (and across closely related species) is partitioned across geographic space is the main focus of the field of phylogeography**. A comparison of this genetic diversity between different populations provides us with unique insights to the history of these populations.

For example, a comparison of the genetic diversity of the different human populations shows us that not only do African populations show the most genetic diversity, the genetic diversity of all other human populations are a subset of this African diversity. This has led us to conclude that anatomically modern humans (*Homo sapiens*) originated in Africa, and spread out from there to colonize the rest of the world. This historical movement (and all subsequent ones) are recorded in the patterns of geographic distribution of genetic diversity. And it's not just migrations - every single demographic event in our history, be it an increase or decrease in population, has left an imprint on our genetic diversity. As you can see, a lot can be said based on the partitioning of genetic diversity!

**Reconstructing the history of life on earth using phylogenies**

Diversity is ultimately determined by speciation and extinction. The rates of speciation and extinction are not uniform across clades

Rates of speciation and extinction also

vary across space and time, and together determine the how species diversity is accumulated.

Sometimes rates vary over time, and in certain periods there is an exponential increase in number of species. This can be seen in a lineage-through-time plot

Sometimes some regions are associated with higher speciation rates resulting in greater diversity. Eg. tropical regions

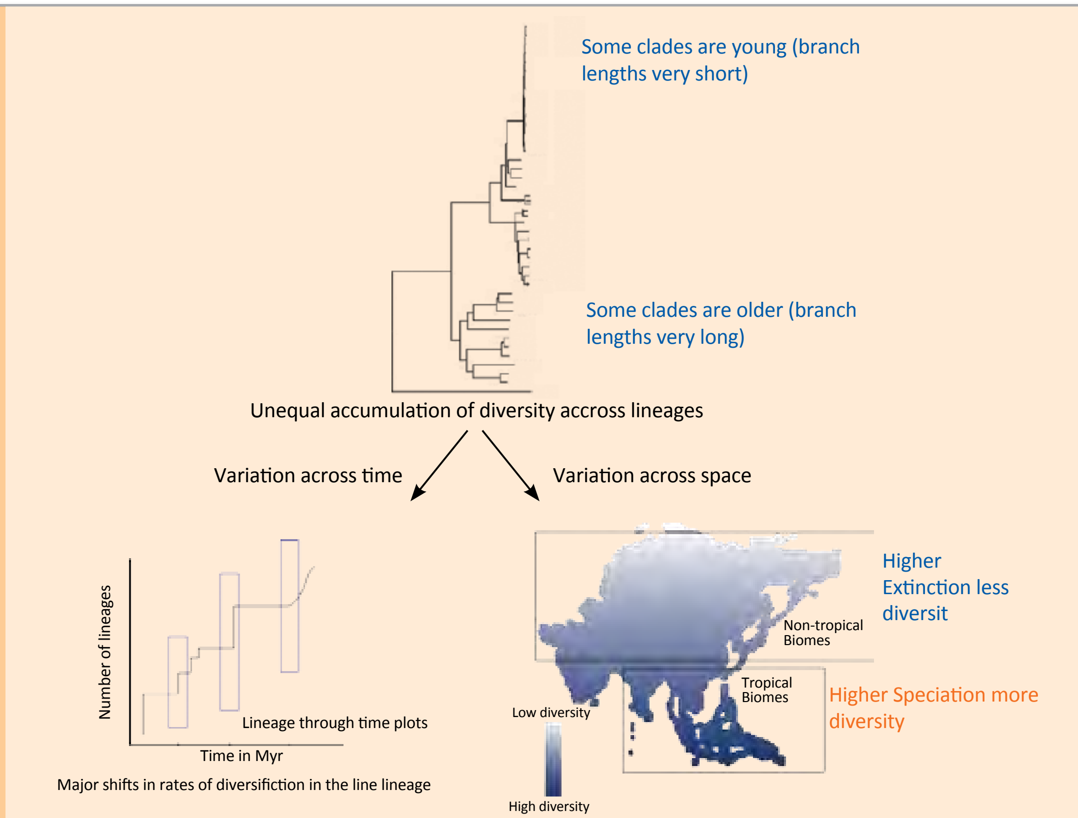



**Figure 4.** We can reconstruct the history of life on Earth using phylogenies.

**Gene flow:** When individuals migrate between populations, they also carry any genetic variation that may be unique to their population to the new population. Thus migration results in the mixing of genetic variation, and prevents populations from becoming very different. This is therefore also called 'gene-flow'.

**Alleles:** Variant forms of a gene. Each gene occurs in two copies in every human. If the two copies are identical, then the person is homozygous, and if different heterozygous. Any individual can have only up to 2 alleles of a gene, while a population can have multiple alleles.

**Mitochondrial DNA:** The mitochondrion is an organelle that is found within the eukaryotic cell. These have their own small genome that codes for some proteins used within the mitochondrion. This DNA is called mitochondrial DNA, and is inherited only through women/mothers (as the sperm does not contain mitochondria when it fuses with the egg).

**Cytochrome b:** A gene that is located in the mitochondrial genome, and codes for a protein that is an important part of the oxidative pathway.

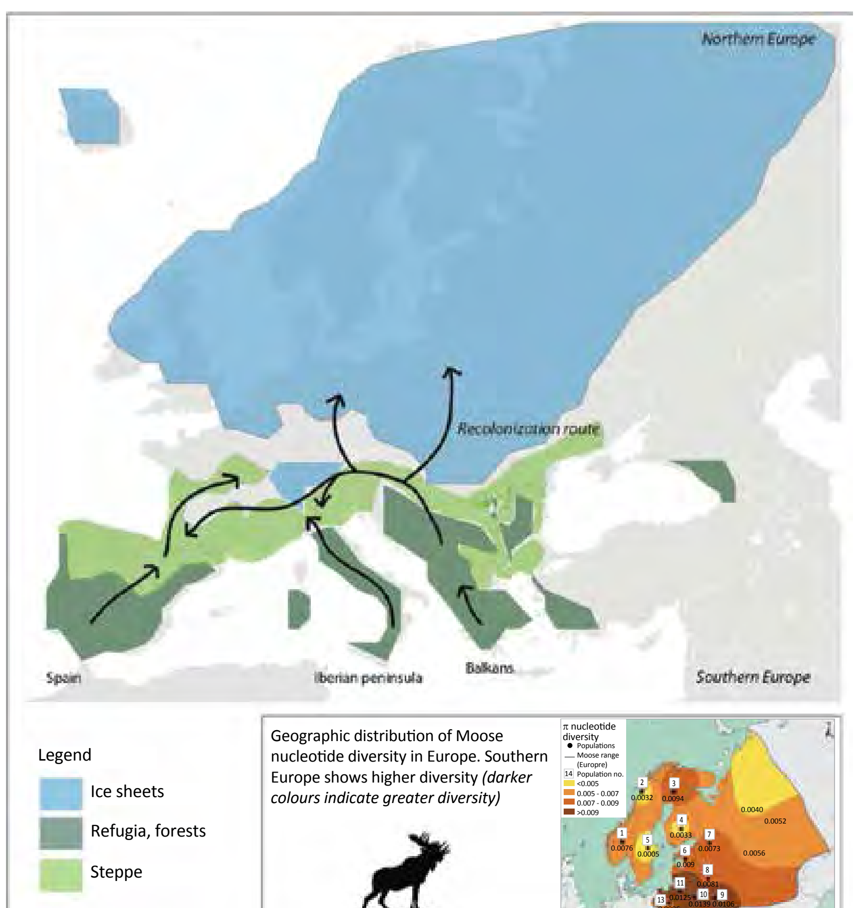
**Single nucleotide polymorphisms (SNP's):** Every difference in nucleotides between two individuals is an SNP. It is the most common type of difference between any two genomes.

In another example, a recent study attempted to estimate the genetic diversity of different tiger populations - in southern, western and central India. India has the largest number of wild tigers in the world, now restricted to pockets of forests across the country. Based on an analysis of shared and unique genetic diversity, scientists were able to quantify gene flow (as a proxy for migration or movement of individuals across populations) between the different Indian tiger populations, and determine if there was a change in the demographic histories of each population. This study indicated a decline in tiger populations as recently as 200 years ago (probably due to the practice of bounty hunting in the British Raj). Thus, just like a phylogeny, we can also infer the timing of demographic (population increase, crash etc.) events.

The confidence with which we can infer past events has been particularly aided by the development of the coalescent theory. This theory relates contemporary allele frequencies (distribution of alleles) in a population to the demographic history of the population, and has been applied to build 'gene-genealogies'. To give a simple analogy, these gene genealogies are family histories and animal pedigrees, only that these are at the scale of

**Phylogeographic patterns in Europe**

For the past 2.4 Mya, ice sheets have expanded and contracted at a regular rate over most of the temperate region, leading to global effects on distribution of biota. Particularly i Europe, ice sheets occupied most of the northern continent. This resulted in species being restricted in the non-glaciated regions in the south and subsequently recolonizing northern Europe when the ice-sheets melted. This was inferred by studying the genomes and the genetic diversity of populations across Europe, especially in Iberian peninsula, Spain and the Balkans showed higher genetic diversity than northern Europe. This suggests that southern Europe acted as glacial refugia for many of these species (Figure 3). This contraction and expansion in geogrpahic range and populationsize thus had consequences to the genetic diversity of the different populations of the species.




Map modified from http://www.metatech.org/

genes and alleles. In many ways this is parallel to how phylogenetics works, except that gene-genealogies are limited to those allele frequencies that are influenced by population growth or decline. By mapping the history of the alleles in a population, one can understand, among other things, if populations have shown an increase or decrease in size over time.

Demographic history (population growth and decline) and migration patterns of species were initially studied through the geographic distribution of cytochrome b/mitochondrial DNA haplotypes (a set of DNA variations that tend to be inherited together). These early studies were based on one or few molecular markers targeting small portions of the genome. This limited clarity and the detail with which one could understand population subdivision and gene flow. Moreover, cytochrome b, being an important gene, also shows lower mutation rates. Subsequently, the use of microsatellite (nuclear) data, based on many more loci, offered more powerful ways to detect patterns. Microsatellites are regions of the genome that are largely characterized by repeated units of nucleotides. Owing to their genetic composition, they tend to mutate at much higher rates than cytochrome b or other genes. This allows them to rapidly accumulate mutations over shorter time periods, giving us a peek into more recent population and demographic patterns as well. Today, thanks to advances in genetic methods especially those relating to genomic data and analyses (including single nucleotide polymorphisms), we have more power to detect demographic history. With genomic data one can access much more of the genome, and obtain signatures of more recent events. Not just that – genetic data has become far more accessible because of decreased costs of sequencing as well as the advances in computing.

## Conclusion

DNA is an excellent repository of history. Phylogenetics and phylogeography help us read and interpret this history of lineages and populations. In other words, they help us piece together the 'history' in the natural history. However, we cannot go back in time to observe our ancestors, or verify the phylogenetic trees that we build or the demographic histories we reconstruct. Thus, every phylogenetic tree and gene-genealogy is viewed as a hypothesis about the relationships between taxa and the patterns of branching. This is also why phylogenetic trees can change in the face of better or newer data.

Today, the genetic tools available to us have given us unprecedented access to, and an understanding of, the history of lineages, species and populations. DNA-based phylogenetic and phylogeographic approaches have revolutionized our understanding of the natural world and the processes that give rise to natural patterns. While there is a lot that we don't know yet, with better techniques, we can hope to learn more!

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**Krishnapriya Tamma** completed her PhD National Centre for Biological Sciences, TIFR Bangalore. She is interested in large-scale patterns of species distributions, and the factors that influence them. Her PhD work focused on investigating biogeographic patterns of small mammals in the Himalayas. She can be contacted at priya.tamma@gmail.com.

i wonder...

# Write for us

*I wonder* is a magazine for middle school science teachers. This not-for-profit effort is published twice a year - June and December, and available in free online and print formats. Each issue is originally available in English, and later translated into Hindi and Kannada.

We are always on the lookout for articles that capture new perspectives to the teaching and learning of science, building on concepts covered in middle school curricula. Submissions from practicing science teachers and teacher educators are particularly welcome. We'd like to read more about the methods, activities, and examples you've tried and tested in your classrooms to engage the curiousity and imagination of your young learners.

Apart from a theme section that is unique to each issue, *I wonder* features many non-theme sections that are common across issues. Some of these non-theme sections include:

| | |
|---|---|
| The Science Lab | Tried-and-tested thought/practical experiments to teach a concept. |
| Life in Your Backyard | Concepts and activities to use immediate surroundings for ecological literacy. |
| Science Online | Ideas and activities to use an open-access online resource as a teaching aid. |
| Earth Matters | Ideas, activities and experiments in education for sustainability |
| Annals of History | The history of one major scientific idea/innovation/concept. |
| Serendipity | The story of an accidental scientific discovery. |
| Biography of a Scientist | Her life and times through the prism of her contribution to science. |
| Myth or Fact | Identifying and addressing common mental models through science. |
| Book Review | Review of a book that can add to the teaching/learning of science |
| Indian Science Facility | An introduction to its history and purpose. |
| Hot off the Press | Why recently reported scientific work has grabbed headlines. |

Can't find a match? Get in touch with us. We'll help you identify the section that the article you'd like to write fits best. Our word limit for most articles is between 2000-2500 words.

We accept submissions throughout the year, but ideas for articles in the December 2016 issue must reach us latest by the 31st of July, 2016. So, hurry - please send a brief outline (< 500 words) and a bio (<100 words) to iwonder.editor@azimpremjifoundation.org. We'll get in touch with you as soon as possible.

**The Editors.**

AABE
Asion Association for Biology Education

# 26th Biennial Conference of the Asian Association for Biology Education Goa, India

## on Trends in Biology Education & Research: Practices & Challenges

**September 20 - 23, 2016**

**About AABE:** The Asian Association for Biology Education (AABE) is a not-for-profit educational organization dedicated to the advancement of biology education and the dissemination of information relating to biology education. AABE's principal office address is: Philippine Science High School System, Agham Road, Diliman, Quezon City, Philippines 1104. The first AABE conference was organised in 1966 at Manila, Philippines and 12th AABE was organized in India on December 1988 at Delhi. AABE's lead journal, The Asian Journal of Biology Education (Asian J. Biol. Educ.) is published electronically with ISSN 1447-0209. The Journal may be accessed on: www.aabe.sakura.ne.jp. The journal and the conference proceedings are indexed and archived at UNESCO.

**About 26th AABE 2016:** 26th Biennial conference of the AABE is **organized by:** The AABE, India Chapter & Vidya Prabodhini College of Commerce, Education, Computer & Management, Goa.

In collaboration with:

- Homi Bhabha Centre for Science Education
- Tata Institute of Fundamental Research, Mumbai
- Rayat Education Society, Satara
- Shri Shivaji Education Society, Amravati
- Association of Teachers in Biological Sciences, India
- St. Ann's College for Women, Hyderabad
- The International Centre, Goa, India.

**Theme** | **Trends in Biology Education & Research: Practices & Challenges**

Education across the globe has constantly undergone changes as it tried to meet the expectations and challenges of the society. This is true for Biology education too. A child's first foray into science at the primary level has mainly been through topics from biology. However, there has not been serious and systematic effort on the part of teachers, science education researchers or curriculum planners to make use of this early advantage and build effective Biology Education models at higher levels of education.

Networking of teachers of schools and colleges along with scientists at higher research centers could facilitate to address questions in Biology Education and Research. The focus of this conference is to bring about collaboration among all of the above stakeholders from the Asia-Pacific region to bring about a robust biology education for all.

## Sub Themes

- Learning Biology through Enquiry
- Impact of Local Issues relevant to biology in global scenario
- Strategies for Awareness of Community health through Biology: Ecological Approach to Learn Biology
- Educational Technology for Biology Education
- Classroom Teaching Learning & Assessment
- Current Challenges & New Approaches for Biology Teachers
- Practices & Challenges in Biology Research & Education

## ABSTRACT SUBMISSION

Authors can submit their abstract (500 words) on any sub-theme. There is facility for oral and poster presentations. Log-on to the 26AABE website for abstract submission, policies and screening details: http://www. 26aabe2016.com Submission will be open from April 15, 2016. The final deadline to submit the abstract is **May 31, 2016.**

## Important Deadlines

**Abstract submission:** April 15 to May 31, 2016
**Online Registration:** April 15 to May 31, 2016
**Early Bird Registration:** Before May 31, 2016

**Full Length Paper Submission:** Before August 31, 2016
***Acceptance of abstracts will be intimated on June 15, 2016.***

## Conference Venue

The International Centre, Goa, India

**Website:** http://www.26aabe2016.com
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